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COMBUSTION PRODUCT EVALUATION OF VARIOUS CHARGE SIZES
AND PROPELLANT FORMULATIONS

FINAL REPORT

by

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FOREWORD

IIT Research Institute (IITRI) is pleased to submit this final report on the study entitled "Combustion Product Evaluation of Various Charge Sizes and Propellant Formulations" performed under Contract DAMD17-88-C-8006 for the U.S. Army Biomedical Research and Development Laboratory. The program started in October 1987 and the experimental work ended in March 1989. The report contains new information on the nature and amounts of combustion products formed from four gun types and propellant systems not previously available.

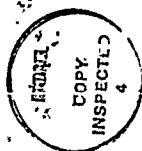
We would like to acknowledge the enthusiasm and support received from Dr. Steve Hoke of the U.S. Army Biomedical Research and Development Laboratory. Dr. Eli Freeman of the Interior Ballistics Division, Ballistics Research Laboratory, Aberdeen Proving Ground, kindly provided theoretical performance calculations on some 30 propellant types. Finally, we offer our thanks to the following personnel: Mr. Chilean Smith, Mr. Cecil E. Martin, Mr. Robert Schnell, Mr. Dewey Collins, Mr. Thomas Dieter, Mr. Jim Andrew, Mr. Gary Hoss, and Ms. Sharon L. Hickey of the Combat Systems Test Activity, Advanced Systems Division of Aberdeen Proving Ground, without whose help and cooperation this study could not have been performed.

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Respectfully submitted,
IIT Research Institute

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IIT RESEARCH INSTITUTE

EXECUTIVE SUMMARY

Maintenance of the soldier's health and mental acuity on the battlefield is of obvious importance to the U.S. Army. Exposure of the soldier to propellant combustion products, both gaseous and particulate, represents a potential health hazard.

Conventional nitro-based propellants are known to produce relatively large amounts of nitrogen, hydrogen, water, carbon monoxide and carbon dioxide and smaller amounts of nitrogen oxides and ammonia on combustion. If sulfur is present in the propellant mix, small amounts of hydrogen sulfide and sulfur oxides are also formed. In enclosed weapon systems, such as tanks, inadequately designed ventilating systems could subject the crew to dangerous toxic gas exposure.

In a recent study for the U.S. Army Medical Research and Development Command, the combustion products from an M16 rifle firing rounds containing WC844 propellant were subjected to a rather detailed chemical analyses. A large number of trace chemical species, volatile organics and PAHs were identified in addition to the more abundant combustion products noted above. Computer modeling of the combustion product distribution showed good agreement with experiment for the major combustion products H_2 , CO, CO_2 , and N_2 based on the concept of "frozen equilibrium", but was of more limited value in replicating concentrations of the minor species such as HCN, CH_4 , and NO_x .

The present program had several objectives all related to the chemical characterization of gun propellant smoke:

- (a) Are the qualitative and quantitative yields of combustion products from a given gun propellant in any way related to the gun caliber?
- (b) Are the qualitative and quantitative yields of combustion products from a given caliber gun dependent on the propellant type?
- (c) Is computer modeling of gun propellant combustion product distribution a realistic approach for determining the real world combustion product distributions?

- (d) Are combustion product distributions determined in breech gases, the same as those present in spent shell casings?
- (e) Are combustion product distributions in gases sampled from a bore evacuator indicative of a composition that might be expected if the breech gases were subjected to the phenomenon of muzzle flash?

Originally, it was hoped that definitive answers could be obtained to all the above questions. However, very early in the program it became evident that although the experiments required to obtain answers to (a) and (b) above were conceptually straightforward, practically they would be extremely expensive to perform since special propellant formulations (non-standard) would have to be manufactured. Accordingly, the decision was made early in the program to study combustion product yields from weapons of a variety of calibers using whatever rounds and associated propellants that were available at Aberdeen Proving Ground.

In previous studies by IITRI, the results from thermodynamic computer modeling of propellant combustion product formation were compared to those derived from experimental data. Using the concept of "frozen equilibrium" it was shown that theoretically computed combustion product distributions were in fairly good agreement with experimental values for major products such as CO, CO₂, and H₂ but were of rather uncertain value with respect to predicting the more minor species. The purpose of the present study was to further assess the usefulness of the computer modeling of combustion product distributions with respect to real world behavior.

There have been reports from personnel in the field that emissions from spent shell casings were more objectionable than emissions directly inhaled from the gun breech. The purpose of the present study was to determine if the combustion product emissions from spent shell casings were in any way different from those from the breech.

Finally, it is well known that with many larger caliber guns a phenomenon called muzzle flash occurs. In this situation, the fuel-rich gases in the propellant combustion products on exiting the muzzle undergo a secondary oxidation which changes the composition of the primary propellant combustion products. Since military personnel may be exposed to the muzzle flash gases, it was of interest to determine their composition. Due to severe over-

pressures that result on firing large caliber guns, sampling combustion products from the muzzle gases is extremely difficult. A suggestion was made that the gases contained in a bore evacuator may undergo oxidation similar to that occurring in muzzle flash and thus provide a relatively simple means of determining muzzle gas compositions. An attempt was therefore made to analyze samples of gas extracted from a bore evacuator on a 155 mm caliber gun.

Combustion Product Distribution Determined for Breech, Spent Casing, and Bore Evacuator Gun Smoke Samples

At the initiation of the program a detailed report⁽⁴⁾ was prepared entitled "Sampling and Analytical Procedures Prepared for the In Gun Propellant Combustion Product Characterization" that described the sampling and analytical procedures to be used in the program. The methods proposed were largely based on IITRI prior experience in the subject area. The report has been accepted as an end product of the program and will not be further discussed here.

In the program, sampling and analytical procedures noted in the above report were implemented to obtain combustion products from 25, 105, 120, and 155 mm caliber guns firing rounds containing WC890, M30, JA2, and M30A1 propellants, respectively. Combustion gases were sampled from the breech on all guns, from spent casings of 25 mm and 105 mm caliber guns (the 120 mm round has a combustible cartridge case, and the 155 mm round uses a bag charge neither of which has a casing to be sampled), and from the bore evacuator on a 155 mm caliber gun. To a greater or lesser degree the following species were quantified: (1) volatile inorganic gases and methane: CO_2 , CO , H_2 , CH_4 , HCN , NH_3 , H_2S , NO_x , and SO_x ; (2) aldehydes: formaldehyde, acetaldehyde, acrolein/acetone, propionaldehyde, crotonaldehyde, isobutyl aldehyde, benzaldehyde, and hexanaldehyde; (3) polynuclear aromatic hydrocarbons: phenanthrene, anthracene, pyrene, benz-a-anthracene, chrysene, benz-b-fluoranthene, benz-k-fluoranthene, benz-a-pyrene, and benz-ghi-perylene; and (4) selected volatile organics: benzene, acrylonitrile, ethylbenzene, toluene, pyridine, styrene, cyanobenzene, and naphthalene. The analytical data for the species have been presented in their final form in terms of the ratio of the moles of analyte per mole of carbon monoxide in the sampled combustion gas. Carbon monoxide was chosen as the reference gas for the following reasons:

- (1) Thermodynamic propellant combustion product calculations indicate that all commonly used propellants generate significant quantities of carbon monoxide, up to 40 mole % of the total gaseous combustion products.
- (2) Background concentration levels of CO are low, probably <5 ppm at Aberdeen Proving Ground. Thus CO may be used as a unique marker for the combustion product gases.
- (3) Carbon monoxide concentrations are often regularly reported in environmental studies related to gun systems. These data in conjunction with those generated in this study allow species concentrations to be determined in the absence of specific measurements for the species and permit likely exposure levels to be estimated.
- (4) The data in this form were readily compared with computed values of the same ratios and permit the determination of temperatures at which equilibrium is "frozen in" the system.

Many new experimental data were generated on propellant combustion product/CO ratios, but for reasons already noted, few definitive conclusions could be made with respect to their magnitude and relationship to propellant type and gun caliber. The following conclusions appear valid:

- (1) For the species studied the composition of the combustion products found in the breech and spent casing samples appeared to be essentially identical, both qualitatively and quantitatively.
- (2) Residual combustion products sampled from the bore evacuator appeared to have the same qualitative and quantitative composition as those sampled from the breech. The effects of muzzle flash on the composition of breech combustion products cannot be determined by sampling gases from the bore evacuator.
- (3) Combustion products were sampled and analyzed from four different caliber weapons each using a different propellant. Under these conditions, it is clearly not possible to relate combustion product/CO ratios to caliber or propellant type dependencies.
- (4) The present data, taken in conjunction with previous IITRI studies, strongly suggest that all propellants containing similar elements will produce qualitatively similar combustion products. The relative amounts of these major and minor species will depend on the propellants' initial stoichiometry reaction kinetics, and on other factors at present not clearly understood.

- (5) Although the combustion product data generated in the present program are unique to the gun and propellant combination sampled, they can probably be used to provide order of magnitude estimates for the composition of combustion products formed in other weapon and propellant systems.

Computer Modeling

Computer modeling of propellant combustion product distribution based on thermodynamic equilibrium calculations was performed for the four propellants studied experimentally and for an additional twenty-six commonly used gun propellants (major ingredients only). These data will be given to Dr. Steve Hoke, contracting officer's representative, at the termination of the program. Using the experimental data generated in the program, combustion product ratios, CO_2/CO and H_2/CO obtained for the four propellants, WC890, M30, JA2, and M30A1 were compared to computed ratios at a series of temperatures in the 1500-1000 K temperature range. Only for the M30 propellant were the ratios consistent with the computed values at a unique temperature (≈ 1400 K) indicative of equilibrium for these three species being "frozen in" the system at the same temperature. For the other propellants, it appeared that at no single temperature would result in the computed and experimental CO_2/CO and H_2/CO ratios being in agreement. Current wisdom holds that all three species should be at equilibrium at some temperature in the range 1500-1000 K, a belief not supported by the data. However, it is noted that for all four propellants studied, each propellant mixture contained significant quantities of other combustible and non-combustible ingredients, notably primers, igniters and flash suppressants. A second series of computations was made to determine combustion product distributions resulting when all the ingredients in the propellant formulations were included. In general, the results from these calculations were little different from those of the earlier calculations based on the pure propellants only. The most notable differences related to the prediction of sulfur compounds forming in the M30 and JA2 propellant combustion products when including all the propellant ingredients in the computation as opposed to their predicted non-existence in the computations made on the pure propellants only.

For the M30 propellant, computed (at an assumed frozen equilibrium temperature of 1,400K) and experimental combustion product ratios for a number of minor species were compared and found to differ by factors ranging from a low of 6 (CH_4/CO) to a high of 2×10^5 (NO/CO). These findings imply that chemical equilibrium for these trace species is "frozen in" at temperatures different from those of H_2 , CO , and CO_2 . For trace species in the other three propellants studied, ignoring the concept of "frozen equilibrium" and trying to obtain the best match between the calculated (any temperature in the range computed) and experimental combustion product ratios, differences ranged from 2 to 10^6 . It is concluded that computations of propellant combustion product distributions using equilibrium thermodynamic calculations are at best of very limited value in predicting real world propellant behavior.

FUTURE STUDIES

During these studies, difficulties were experienced with a number of the sampling and analytical procedures used to determine gun smoke compositions. The methodologies used in the study were largely based on recognized air sampling procedures and failed apparently due to the multiplicity of species present in gun smoke compromising sample storage and analysis integrity. Further reliable characterization of trace propellant combustion products will require development and validation of more suitable sampling and analytical methodologies.

An attempt during these studies to assess the effects of "muzzle flash" on the composition of the propellant combustion products (with respect to breech gas composition), was not successful. It is thus not clear at the present time if exposure to the muzzle gas (after muzzle flash) is likely to be more or less hazardous than exposure to the breech gases. Attempts should therefore be made to develop sampling and analytical techniques that could be used to determine the composition of the muzzle gas combustion products from large guns that have been subjected to "muzzle flash" effects.

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SYMBOLS AND ABBREVIATIONS

°F	degrees Fahrenheit, unit of temperature
g	gram, unit of mass
GC	gas chromatograph
GC/MS	gas chromatography/mass spectrometry
GMW	General Metal Works PAH sampler
JA2	Military propellant designation
K	Kelvin, unit of absolute temperature
kg	kilogram, unit of mass
l	liter, unit of volume
M30	Military propellant designation
M30A1	Military propellant designation
M68	Military gun designation
M199	Military gun designation
M242	Military gun designation
min	minute, unit of time
ml	milliliter, unit of volume
mm	millimeter, unit of length
μ M	micromoles, unit of mass
N	normality of solution
NO _x	nitrogen oxides, usually NO and NO ₂
P	abbreviation for pressure
PAH	polynuclear aromatic hydrocarbons
psi	pounds per square inch, unit of pressure
SO _x	sulfur oxides, usually SO ₂ and SO ₃
Vol	volume
WC844	Military propellant designation
WC890	Military propellant designation
XM256	Military gun designation

1. INTRODUCTION AND SCOPE OF PROGRAM

Maintenance of the soldier's health and mental acuity on the battlefield is of obvious importance to the U. S. Army. Exposure of the soldier to propellant combustion products, both gaseous and particulate, represents a potential health hazard.

Conventional nitro-based propellants are known to produce relatively large amounts of carbon monoxide and carbon dioxide and smaller amounts of nitrogen oxides and ammonia on combustion. If sulfur is present in the propellant mix, small amounts of hydrogen sulfide and sulfur oxides are also formed. In enclosed weapons systems, such as tanks, inadequately designed ventilating systems could subject the crew to dangerous toxic gas exposure.

In recent studies for the U. S. Army Medical Research and Development Command,⁽¹⁾ and the Dow Chemical Co.,⁽²⁾ the combustion products from an M16 rifle firing rounds containing WC844 propellant were subjected to rather detailed chemical analyses. A large number of trace chemical species were identified in addition to the more abundant combustion products noted above. Computer modeling of the combustion product distribution showed fairly good agreement with experiment for the major combustion products H_2 , CO, CO_2 , and N_2 but was of more limited value in replicating concentrations of the minor species such as HCN, CH_4 , and NO_x .

The primary objective of the present research was the evaluation of small, medium, and large caliber weapons to determine the chemical composition of the breech gases and when possible, emissions from spent casings. The evaluation included chemical analyses from 25 mm, 105 mm, 120 mm, and 155 mm caliber weapons, firing rounds containing propellant types WC890, M30, JA2, and M30A1, respectively. Methodological approaches were proposed and implemented for:

- chemical analyses of breech and spent casing emissions
- determining how the production of minor and trace species scale with the size of charge (four different gun calibers)
- inventorying combustion products from four propellant types and modeling the occurrence of the products.

Analyses of combustion products were directed towards the examination of constituent or compound classes that have proven to be toxicologically significant in related combustion processes (i.e., diesel engine exhausts). These included:

- (1) gaseous aldehydes
- (2) polynuclear aromatic hydrocarbons
 - (a) 3-6 ring PAHs and
 - (b) nitro-PAHs
- (3) gas phase organics
- (4) inorganic gases
- (5) metals

The procedure used to sample and analyze for gas phase organics (GC/MS) was capable of detecting a large number of species, many of which were toxicologically insignificant. A limited number of these species (8) was selected for quantification based on their known toxicological properties.

Computer modeling of the combustion product distributions was carried out for the four propellant systems studied experimentally. In addition, similar calculations were made for a number of other frequently encountered propellant types. Experimental data from inorganic (CO , CO_2 , and H_2) breech gas analyses were used in conjunction with the computed combustion product distributions for the same gases to determine the "characteristic temperature" at which equilibria became "frozen in" for these species. The computed combustion product distribution at the "characteristic temperature" for some of the trace species was compared with that determined experimentally to assess the value of computer modeling in predicting trace species concentrations.

A limited effort was made to assess the impact of muzzle flash on gun combustion product distributions (compared to breech sampled combustion product distributions) by sampling combustion products from the bore evacuator of a 155 mm cannon.

Finally, the overall results obtained during the course of the program were presented to the U. S. Army Medical Research and Development Command both in documented (this final report) and oral presentation forms.

The remainder of this report is devoted to a description of the work accomplished during the course of the program and the conclusions derived therefrom.

IIT RESEARCH INSTITUTE

2. GUN TYPES AND PROPELLANTS STUDIED EXPERIMENTALLY AND THEORETICALLY

2.1 INTRODUCTION

A major interest of the program was to discover:

- (1) Are the qualitative and quantitative yields of gun combustion products from a given propellant in any way related to gun caliber?
- (2) Are the qualitative and quantitative yields of gun combustion products from a given caliber of gun dependent on the propellant type, i.e., single, double, or triple-base propellant compositions?

Although the experiments required to obtain such information are conceptually straightforward, they would be extremely expensive to perform since special propellant formulations (non-standard) would have to be manufactured.

Accordingly, the decision was made early in the program to study combustion product yields from weapons of a variety of calibers using whatever rounds and associated propellants that were available for sampling at Aberdeen Proving Ground during the course of the program.

2.2 GUN TYPES AND PROPELLANTS FROM WHICH COMBUSTION PRODUCTS WERE SAMPLED AND ANALYZED

Table 1 lists the gun types (military designation), calibers, propellant types (military designation) and compositions. The information with respect to gun and propellant types was obtained from the "Artillery Ammunition Master and Reference Calibration Chart", Report No. 1375, 28th Revision, June 1987 prepared by the Test Division, Directorate of Material Testing, U. S. Army, Jefferson Proving Ground. Four gun calibers, 25, 105, 120, and 155 mm, and four major propellant types, WC890, M30, JA2, and M30A1, were involved in the sampling program. In addition to the major propellant present in each round, quantities of primer/igniter materials were present, 8.15% (M68), 1.38% (M199), 0.38% (M242), and 7.03% (XM256). In addition to the active fuels and oxidizers present in the propellant charges, there were also a number of "inert" inorganic materials, flash suppressants (metal sulfates), and bore erosion suppressants (lead foil and TiO_2).

TABLE 1. GUN TYPES AND FORMULATIONS OF GUN PROPELLANTS FROM WHICH COMBUSTION PRODUCTS WERE SAMPLED

Gun Type (Bore mm)	Propellant and (Weight)	Chemical Composition	Wt. %
M242 (25)	WC890 (32 g)	Nitrocellulose ($C_6H_{7.549}N_{2.451}O_{9.901}$)	79.980
		Nitroglycerine ($C_3H_5N_3O_9$)	10.200
		Diphenylamine ($C_{12}H_{11}N$)	1.110
		Dibutylphthalate ($C_{16}H_{22}O_4$)	7.650
		Dinitrotoluene ($C_7H_6N_2O_4$)	0.080
		Graphite	0.140
		Potassium Sulfate (K_2SO_4)	0.710
		Sodium Sulfate (Na_2SO_4)	0.060
		Calcium Carbonate ($CaCO_3$)	0.070
		M115 (Primer Igniter 0.121 g)	Nitrocellulose ($C_6H_{7.395}N_{2.451}O_{9.901}$)
Boron	45%		
Potassium Nitrate (KNO_3)	45%		
M68 (105)	M30 (6.133 kg)	Nitrocellulose ($C_6H_{7.549}N_{2.451}O_{9.901}$)	27.900
		Nitroglycerine ($C_3H_5N_3O_9$)	22.420
		Nitroguanidine ($CH_4N_4O_2$)	47.540
		Ethylcentralite ($C_{17}H_{20}N_2O$)	1.490
		Cryolite (Na_3AlF_6)	0.300
		Carbon	0.100
		Alcohol (C_2H_6O)	0.250
M120 Electric (Primer, Strand Benite 0.5 kg)			

TABLE 1. GUN TYPES AND FORMULATIONS OF GUN PROPELLANTS FROM WHICH COMBUSTION PRODUCTS WERE SAMPLED (Continued)

Gun Type (Bore mm)	Propellant and (Weight)	Chemical Composition	Wt. %
XM256 (120)	JA2 (7.113 kg)	Nitrocellulose ($C_6H_{7.395}N_{2.605}O_{10.209}$)	62.388
		Diethyleneglycol dinitrate ($C_4H_8N_2O_7$)	36.634
		Ethyl centralite ($C_{17}H_{20}N_2O$)	0.250
		Akardite ($C_{14}H_{14}N_2O$)	0.440
		Carbon	0.240
		Barium Oxide (BaO)	0.040
	XM125 (Primer, Strand Benite 0.5 kg)	Nitrocellulose ($C_6H_{7.364}N_{2.636}O_{10.271}$)	39.801
		Potassium Nitrate (KNO_3)	44.080
		Sulfur	6.269
		Charcoal ($C_{8.681}H_{4.962}S_{0.001}O_{1.000}N_{0.027}$)	9.353
		Ethylcentralite ($C_{17}H_{20}N_2O$)	0.498
M199 (155)	M30A1 (11.912 kg)	Nitrocellulose ($C_6H_{7.549}N_{2.451}O_{9.901}$)	27.900
		Nitroglycerine ($C_3H_5N_3O_9$)	22.420
		Nitroguanidine ($CH_4N_4O_2$)	46.840
		Ethylcentralite ($C_{17}H_{20}N_2O$)	1.490
		Potassium Sulfate (K_2SO_4)	1.000
		Alcohol (C_2H_6O)	0.250
		Carbon	0.100
	M82 (Primer, Black Powder 0.022 kg)	Potassium Nitrate (KNO_3)	73.88
		Sulfur	9.97
		H ₂ O	0.30

TABLE 1. GUN TYPES AND FORMULATIONS OF GUN PROPELLANTS FROM WHICH COMBUSTION PRODUCTS WERE SAMPLED (Continued)

Gun Type (Bore mm)	Propellant and (Weight)	Chemical Composition	Wt. %
M199 (155)		Charcoal ($C_{13.21}H_{5.73}S_{0.02}N_{0.01}O_{1.0}$)	15.71
		Calcium Carbonate ($CaCO_3$)	0.14
	Igniter (Black Powder 0.142 kg)		
	Additional:	K_2SO_4 (0.456 kg)	
		Lead Foil (0.157 kg)	
		TiO_2 /wax (0.499 kg)	

The 25 and 105 mm caliber guns had metal cartridge cases, and samples of emissions from these and from the gun breeches were obtained. The 120 mm caliber gun utilized a round with a combustible cartridge case. It was thus not possible to sample emissions from the spent case. The 155 mm gun used bag charges and hence again there was no spent case from which emissions from the main propellant charge could be sampled. The main propellant charge in this gun was ignited by a small cartridge (about the size of an M16 round) which by virtue of its small size was not amenable to sampling in the present program.

2.3 THEORETICAL PROPELLANT COMBUSTION PRODUCT CALCULATIONS

Another major purpose of the present program was to evaluate the usefulness of theoretical propellant combustion product calculations for predicting real world concentrations of the major or trace species in gun propellant combustion products. When the program was initiated, preliminary discussions with personnel at Aberdeen Proving Ground indicated that it would not be possible to determine much in advance which rounds and propellants would be accessible for sampling in the program. Advantage was therefore taken of an offer by Dr. Eli Freedman (since retired) of the Ballistic Research Laboratory to provide us with computer printouts of predicted combustion product distributions for some of the most commonly used propellants based on the Blake Tiger Code. Specific propellants for which data were obtained are presented in Table 2. These computations were made for an isentropic⁽³⁾ expansion of the combustion gases in the gun barrel, assuming attainment of thermal equilibrium in the process as the temperature of the expanding gases drops. Since the process takes place extremely rapidly, in reality, equilibrium for different species becomes "frozen in" at different temperatures due to differing kinetic reaction rates. In this program, experimentally measured combustion product ratios for H_2/CO and CO_2/CO , are compared to computed values to estimate the temperature at which equilibrium becomes "frozen in" for the species. The resulting temperature is then used to predict the ratios CH_4/CO , HCN/CO , NH_3/CO , and NO/CO and for other minor species. These ratios are compared to the experimental values to assess the reliability of the computed values.

TABLE 2. GUN PROPELLANTS FOR WHICH THEORETICAL COMBUSTION PRODUCT DISTRIBUTION CALCULATIONS WERE MADE

Propellant Designation				
M1	M9	M26	M31E1	IMR
M1A1	M10	M26E1	WC870	RAD1-2
M2	M14	M30	JA2	PYRO
M5	M15	M30A1	JA2S110	FRED-R
M6	M17	M30A2	JA2 (Radford PE-792-3)	BENITE
M8	M18	M31	UKHE	BLACK/POWDER

It is noted at this point that the theoretical propellant combustion product calculations are usually made for the "main" propellant in the formulations shown in Table 1. It does not take into account the presence of primer and/or igniter in the charge, or additional materials such as K_2SO_4 , lead foil or TiO_2 /wax, found in the bag charges of the M199 gun. During this study, calculations were made of product distributions that resulted when these latter additives were included with that of the main charges in the computation inputs.

Finally, it is noted that the theoretical propellant combustion product calculation printout will be given to Dr. Steve Hoke, program technical representative for the U. S. Army Medical Research and Development Command, at the oral technology transfer meeting held at Fort Detrick 18 August 1989.

3. PROPELLANT COMBUSTION PRODUCT SAMPLING AND ANALYTICAL PROCEDURES

3.1 INTRODUCTION

A primary object of the program is to relate the amounts of combustion products formed in one gun/propellant system to those formed in other systems and be able to compare these data to theoretically computed values. To do this, it was necessary to relate the amount of material sampled and analyzed to the amount of CO, CO₂, and H₂ in that sample. The relative amounts of these three gases were used to establish the temperature at which equilibrium is "frozen in" the combustion products gases through thermodynamic equilibrium computer calculations on the combustion product composition for the specific propellant formulation used. Using this approach, all chemical species formed in the combustion products could be directly related to the amount of CO, CO₂, or H₂ present in the breech gas. Carbon monoxide concentrations are often monitored routinely when assessing health problems associated with weapon systems. Such data, when coupled with the chemical analyses made in the program, will allow assessments to be made of likely operating personnel exposures to a large number of trace species.

The first task to be completed in this program was the preparation of a detailed report⁽⁴⁾ entitled "Sampling and Analytical Procedures Proposed For Use In Gun Propellant Combustion Product Characterization." The sampling and analytical procedures proposed in that report for use in the program were based on IITRI's prior work for Fort Detrick⁽¹⁾ and for the Dow Chemical Company⁽²⁾ in gun smoke analyses. Since this report has been accepted as a product of the present study, a detailed description of the procedures will not be repeated here. Rather a very brief description of the basic analytical procedures will first be given together with any subsequent modifications. This will be followed by some photographic documentation of the actual field sampling equipment used with the various weapons.

3.2 ANALYTICAL PROCEDURES

1. Permanent gases: H_2 , CO, CO_2 , and CH_4 - Gas chromatography, Carle Model 111-H 196A gas chromatograph fitted with thermal conductivity detector. Combustion gases collected in 1-liter glass flasks (nominal volume) or metal containers (281 ml). Matheson Certified gas standards of the above gases in nitrogen were used to calibrate and verify the calibration of the GC.
2. HCN. Combustion gases allowed to contact 10 ml, 0.01N sodium hydroxide solution in 1-liter glass flask. Cyanide ion analyzed at TEI Analytical of Niles, Illinois using EPA Method EPA 600/4-79-020 (1979). Control or spiked samples run concurrently to verify analytical integrity.
3. NH_3 . Combustion gases allowed to contact 10 ml, 0.01N sulfuric acid in 1-liter glass flask. NH_4^+ ion analyzed at TEI Analytical of Niles, Illinois using a method based on Nessler's reagent. Control or spiked samples run concurrently to verify analytical integrity.
4. $NO_x + SO_x$. Combustion gases allowed to contact 10 ml, 0.01N sodium hydroxide solution plus 2 ml of 30% H_2O_2 in 1-liter glass flask. Resulting NO_3^- and SO_4^{2-} ions measured on a Dionex Ion Chromatograph. Standard solutions of NO_3^- and SO_4^{2-} made from ACS Reagent Grade materials used to calibrate and verify integrity of analytical data during each set of analyses.
5. H_2S . Combustion gases allowed to contact 10 ml of 0.01M $CdSO_4$ + STRactan (10) solution in 1-liter glass flask. Collected CdS was determined spectrophotometrically by measurement of the methylene blue produced by the reaction of N,N-dimethyl-p-phenylenediamine and ferric chloride. This is the NIOSH Method S4. According to the NIOSH Method S4, the solution used to trap the H_2S as CdS is used directly to determine its S^{2-} ion content. Due to interferences present in the solution it was found necessary to filter off and wash the precipitated CdS under an argon atmosphere prior to making the analysis for the sulfide ion. Standard

sulfide solutions prepared from ACS reagent grade sodium sulfide used to calibrate spectrophotometer.

6. Aldehydes. Combustion gases allowed to contact 10 ml of 3.1 μ M 2,4-dinitrophenylhydrazine solution in acetonitrile containing five drops of 1N HClO₄ in 1-liter glass flask. The hydrazones were analyzed using a reversed phase HPLC (Waters) system. The following eight aldehydes were quantified; formaldehyde, acetaldehyde, acetone/acrolein, propionaldehyde, crotonaldehyde, isobutyraldehyde, benzaldehyde, and hexaldehyde. Diphenylhydrazene derivatives were prepared at IITRI from the corresponding aldehyde and purified by re-crystallization. These derivatives were used to calibrate the HPLC prior to the analyses. Control and spiked samples were run to assess analytical integrity and recoveries.
7. Gas Phase Organics. Combustion gases, 281 ml, were adsorbed onto Tenax collectors at ≤ 200 ml/min sampling rate. Each collector was spiked with an internal standard and after desorption the collected species were analyzed by GC/MS both qualitatively and quantitatively. After consultation with the sponsor, the following eight species were selected for quantification based on their known toxic properties; benzene, toluene, ethylbenzene, styrene, naphthalene, propenitrile, pyridine, and cyanobenzene.
8. Polynuclear Aromatic Hydrocarbon (PAH). Combustion gases, 10-30 liters were passed through a General Metal Works, PAH collector containing a filter to collect the particulate PAHs and a polyurethane plug to collect the more volatile PAHs at a flow rate of 10 l/min. Usually the material on the filter and polyurethane plug was extracted with methylene chloride and the combined solutions analyzed on a Waters HPLC system. In a few experiments the filter and plugs were extracted and analyzed separately. The following PAHs were quantified; phenanthrene, anthracene, fluoranthene, pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, and benzo[g,h,i]perylene. One attempt was made to analyze a PAH sample from the 120 mm gun for nitro-PAHs but none was definitely found. No further attempts to detect nitro-PAHs

were made on the other weapon systems studied due to the overall complexity of the analysis. The HPLC was calibrated against an NBS certified mixture of the above PAHs (SRM.1687) prior to each analysis.

9. Metal Particulates. Samples (\approx 5 liters of combustion gases) of particulate in combustion gases were collected on filters and analyzed using inductively coupled plasma-atomic emission spectroscopy by TEI Analytical of Niles, Illinois. In a very limited series of tests analyses for the following metals were made; potassium, lead, and titanium.

3.3 FIELD SAMPLING EQUIPMENT AND PROCEDURES

3.3.1 Introduction

Chemical analyses of all gun smoke samples were made in IITRI's Chicago laboratory or at TEI Analytical in Niles, Illinois. The U. S. Army at Aberdeen Proving Ground provided space in a small building (designated Menslab) to store some of the required sampling equipment between tests, for assembling equipment for tests, and for chemical treatment of some samples prior to shipment back to IITRI for analyses. Since some of the sampling containers were rather bulky and fragile, suitable wooden boxes were fabricated for their air transportation between Chicago and Aberdeen. In some cases these boxes were also used to hold the sampling containers (1-liter glass flasks) during the gun smoke sampling experiments.

All the sampling equipment used in the program will become the property of the U. S. Army Medical Research and Development Command at the program's termination for possible subsequent use by the U. S. Army for further field sampling of gun smokes. For this reason, the following photographic and written description of the overall field sampling procedures is presented for the benefit of Army personnel.

3.3.2 Preparation of 1-Liter Evacuated Glass Flasks

The glass flasks (nominal volume 1 liter, actual volume 1.024 liters) used for analyses of H_2 , CO, CO_2 , H_2S , HCN, NH_3 , NO_x , SO_x , and aldehydes were thoroughly washed with distilled water, rinsed with acetone and evacuated to ≤ 1 mm of Hg in Chicago just prior to shipment to Aberdeen. This procedure was used on all flasks except those used for aldehyde analyses. For the latter,

the acetone rinse was replaced by one with acetonitrile. In addition, at this time each flask was fitted with a new silicon rubber/Teflon septum. On the day that the flasks were to be used to obtain gun smoke samples at Aberdeen, the flasks were all re-evacuated to ≤ 0.3 mm of Hg using the arrangement shown in Figure 1.

3.3.3 Breech Gas Sampling With 1-Liter Glass Flasks, Large Caliber Weapons 105, 120, and 155 mm

A typical experimental arrangement used to sample breech gas into 1-liter glass flasks is shown in Figure 2. The breech adaptor in this case is for a 105 mm cannon. The entire assembly was kept behind the gun bunker until after the gun was fired. Immediately after the firing a plastic bag was loosely tied over the gun muzzle to minimize loss of combustion gases from the barrel. The spent shell casing was slowly removed manually (i.e., the automatic spent casing ejector mechanism was disconnected for these tests) to minimize combustion gas loss from the barrel, and the breech adaptor inserted. The valve on the filter holder was closed and the stopcocks on the five glass flasks connected to the Teflon manifold were quickly opened. The valve on the filter holder was opened allowing the combustion gases to be sucked simultaneously into the five evacuated flasks. Prior tests showed that the time required to fill the glass flasks to ambient pressure was approximately 45 seconds. In the study, 90 seconds was allowed for the flask filling (all valves left open). At the termination of the sampling period the stopcocks on the liter flasks were closed and the Teflon lines disconnected. Later in the day the flasks were returned to Menslab. The sixth glass flask, not used in the breech sampling was used to obtain a background air sample either prior to or well after a gun firing. If a particulate sample was being obtained, the filter was removed from the holder and stored in a plastic petri dish for return to Chicago. Depending on the number of rounds to be fired on a particular day and the time available, one, two or three sets of five 1-liter glass flask samples were obtained from one firing of the same round on the 105 mm, 120 mm, and 155 mm caliber weapons.

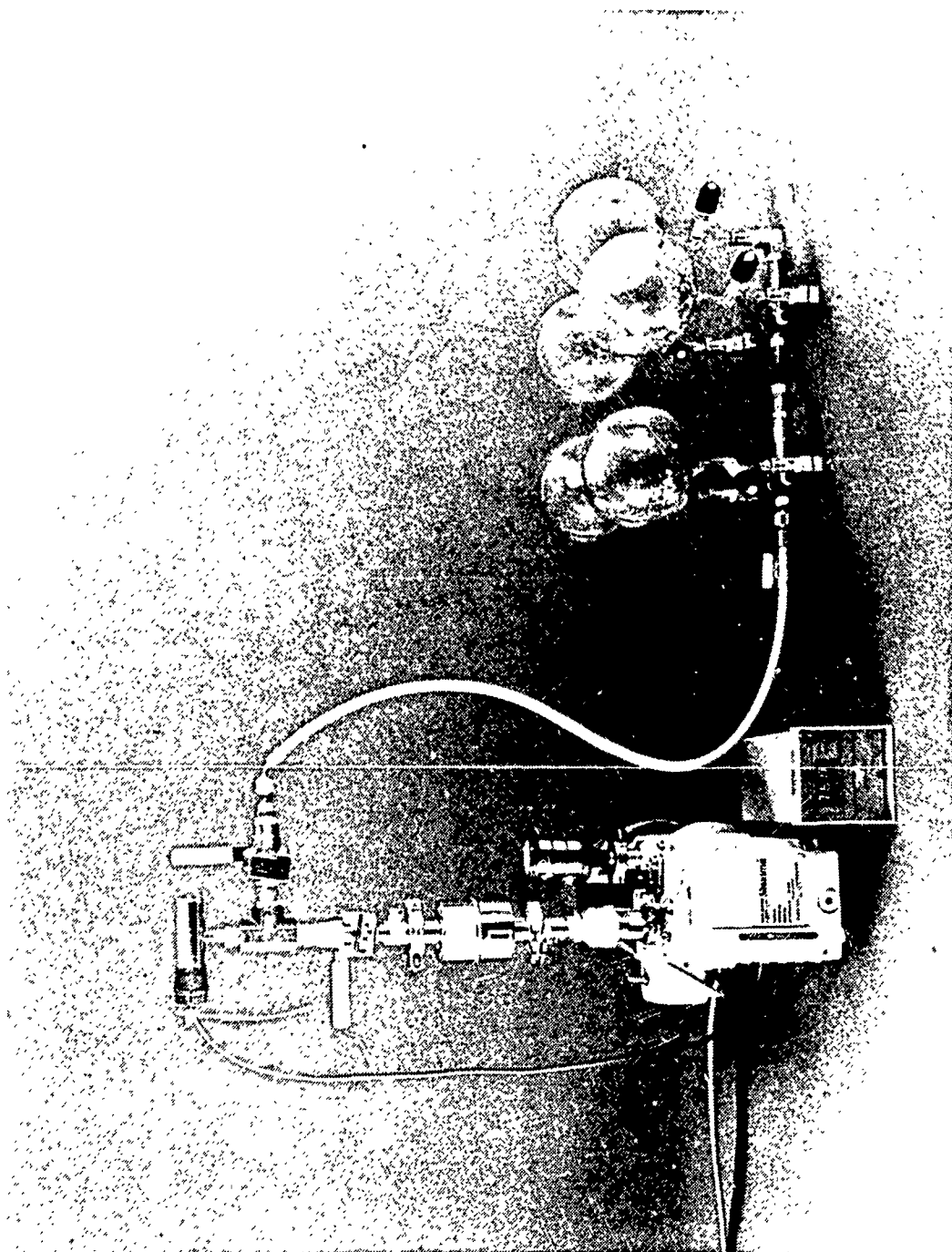


Figure 1. Experimental arrangement used for evacuation of 1-liter glass sampling flasks, showing vacuum pump, thermocouple pressure gauge with digital readout, and manifold for connecting flasks to pump.

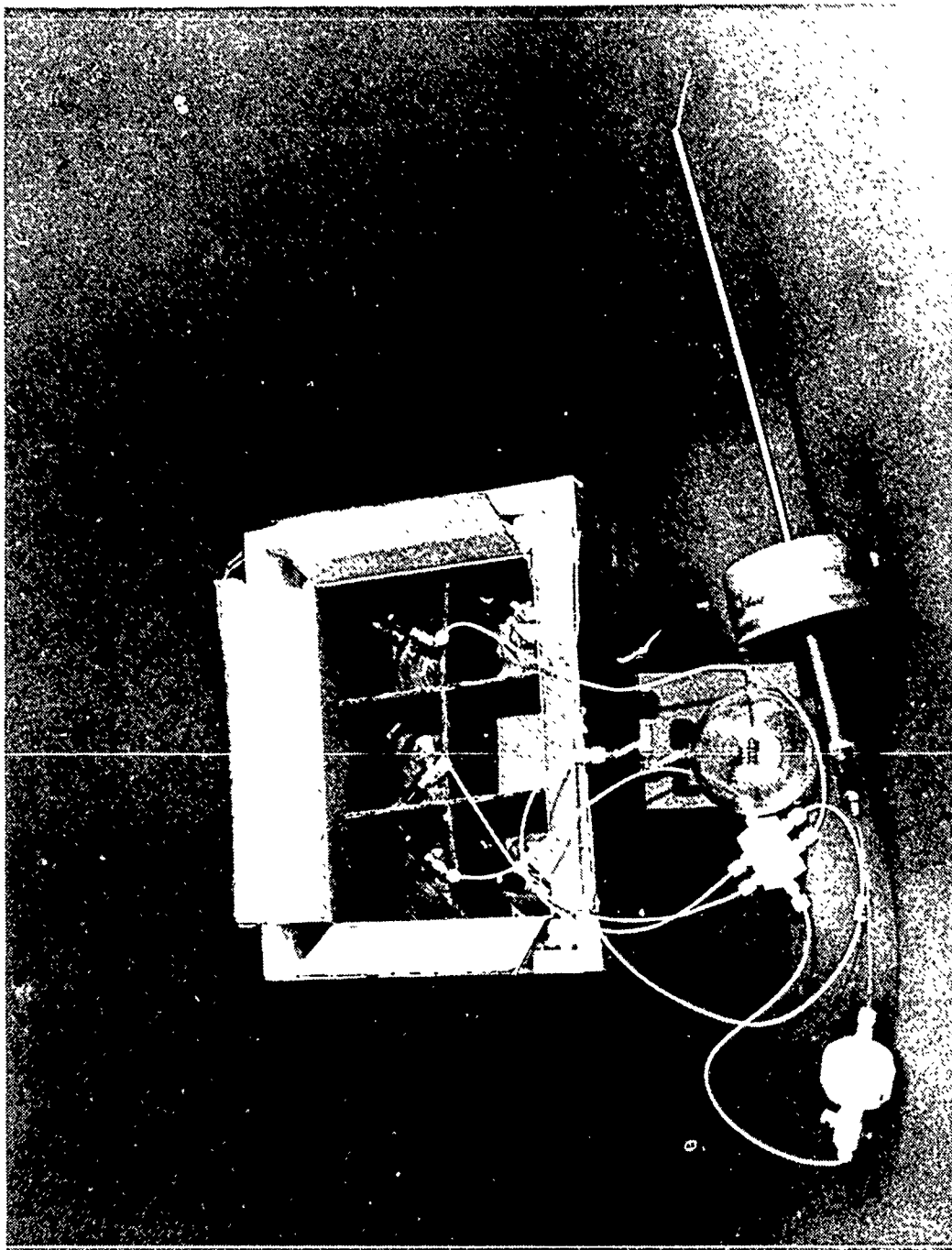


Figure 2. Experimental arrangement used to sample breech gas into 1-liter glass flasks from a 105 mm cannon, showing breech adaptor, particulate filter holder, Teflon manifold, and glass flasks with wooden holding case.

On returning the sets of glass flasks to the Menslab, the chemical reagents were added to the flask using syringe injections of the required volumes through the septa provided. The flasks were secured in their boxes and returned to IITRI at the earliest convenience. This was usually the same day on which the sampling was performed, though in some cases where sampling took place over several days, this was not possible.

3.3.4 Breech Gas Sampling With 1-Liter Glass Flasks, 25 mm Gun

The volume of gas contained in the barrel of the weapon was ≈ 1 liter. It was thus not feasible to collect five 1-liter gas samples simultaneously, without causing excessive dilution of the combustion products with air. Accordingly, each 1-liter glass flask was filled individually after the firing of a single round using a slightly modified sampling system to that described in 3.3.3.

3.3.5 Spent Casing Sampling With 1-Liter Glass Flasks

The experimental arrangement used to obtain combustion gas samples from 25 mm spent shell casing in 1-liter evacuated glass flasks is shown in Figure 3. The spent shell casings from individual firings of the gun were manually withdrawn from the barrel, the aluminum cap on the 5-gallon container raised sufficiently to insert the spent casing into the container, and the cap replaced. This sequence of events was repeated as many as 70 times, at the end of which time the combustion gases were sampled into five 1-liter evacuated glass flasks in the usual way. Depending on the number of rounds fired and the time available, one or two sets of 5-liter samples were obtained from the same batch of collected spent casings. For obvious reasons, no attempts were made to collect particulate samples from the spent shell casings.

105 mm caliber spent shell casings were also sampled with the five 1-liter evacuated glass flasks. The volume in the spent casing was ≈ 5 liters. After firing the weapon the casing was manually removed from the barrel and the aluminum cap, shown in Figure 3 on the 5-gallon container, quickly placed over the spent casing's open end (the cap was a snug push fit on the casing). The contained gas was then sampled simultaneously into the five flask set. Only one set of five flasks was sampled from each 105 mm casing.

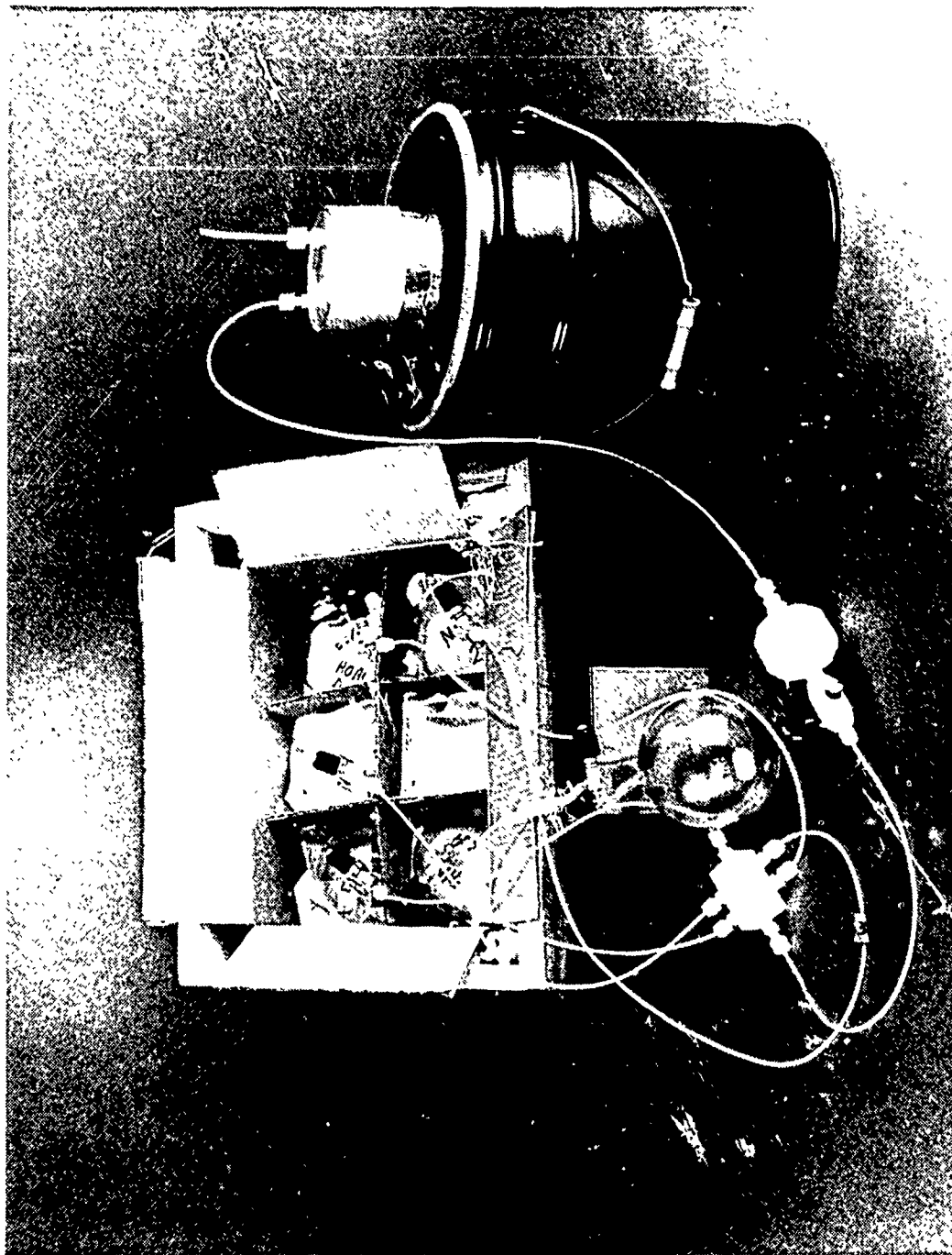


Figure 3. Experimental arrangement used to obtain combustion product samples in 1-liter glass flasks from a 25 mm gun, showing the 5-gallon container used to store the spent casing from multiple firings (as many as 70 per sample).

3.3.6 Breech and Spent Casing Sampling for GC/MS Analyses

A sampling arrangement to collect combustion product gases from the breech of a 25 mm gun is shown in Figure 4. After firing the gun and manually removing the spent casing, the breech adaptor was quickly inserted into the breech. The gases were then sampled via the filter through the Tenax collectors at a controlled rate ≤ 200 ml/min and the non-adsorbed gas collected in the evacuated metal sampling cylinder. (These sampling cylinders were evacuated initially in Chicago and again on the day of use at Aberdeen Proving Ground.) Experience showed that a sampling time of 3 minutes was adequate to ensure filling the metal sampling flask, volume 281 ml, to ambient pressure. After collecting the sample, the Tenax collectors were replaced in their glass transportation containers for shipment to Chicago for GC/MS analyses. The metal sampling flask was sealed and returned to Chicago for analysis of its CO, CO₂, and H₂ contents. Range finding tests on the 120 mm cannon with the Tenax sampling system indicated that the sampling volume of 281 ml was sufficient to obtain the amounts of combustion products required for GC/MS analyses without oversaturating peaks or causing significant breakthrough from the first to the second Tenax collector.

Single spent shell casings from a 105 mm caliber cannon and multiple spent shell casings from the 25 mm caliber gun were sampled for GC/MS analyses of the collected combustion products using procedures analogous to those described in 3.3.5.

3.3.7 Breech Gas Sampling for PAH Analyses

The experimental arrangement to obtain breech gas samples from a 155 mm caliber gun is shown in Figure 5. Two General Metal Work (GMW) PAH samples are shown connected in tandem. The combustion product gases were extracted at 10 liters/min through the samplers into a Teflon bag mounted inside a sealed 30-gallon polyethylene barrel. The Teflon bag was initially deflated. A critical orifice mounted in the top of the barrel and connected to a vacuum pump was used to define the 10 liter/min flow rate through the samplers. After the round was fired, the breech was left closed and the initiator cartridge removed and the breech adaptor inserted. The vacuum pump was actuated for the time required to obtain a 10, 20 or 30 liter sample of gas through the PAH collectors and into the Teflon bag. The PAH samples were disconnected from

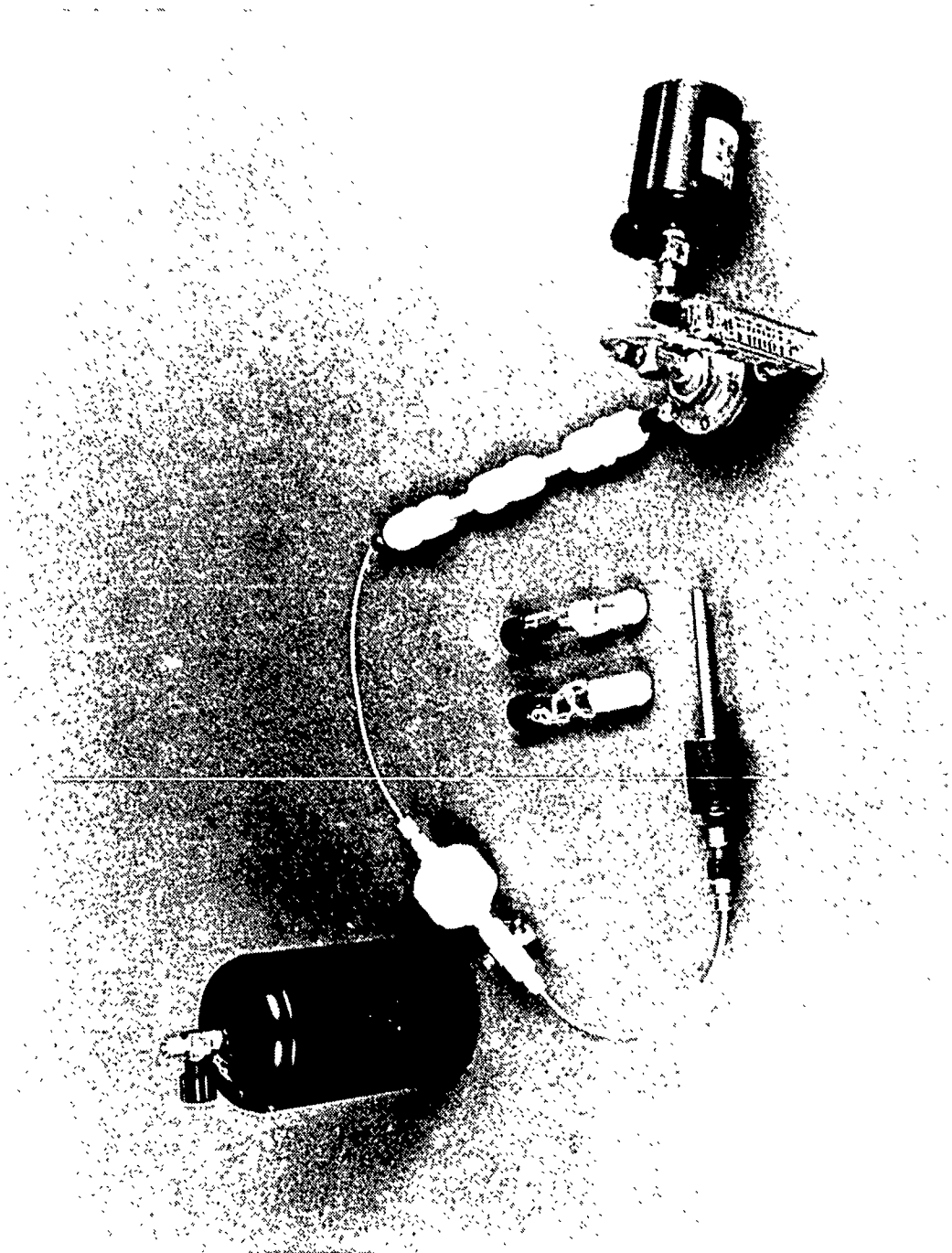


Figure 4. Experimental arrangement used to obtain combustion product samples for GC/MS analyses using Tenax collectors. Figure shows breech adaptor for 25 mm gun, Teflon filter holder, two Tenax collectors in tandem, a flow controller, ~200 ml/min, and evacuated metal flask (volume 281 ml) used to define the sampling volume. Large metal cylinder on left (volume 2154 ml) was only used in some initial range finding studies.

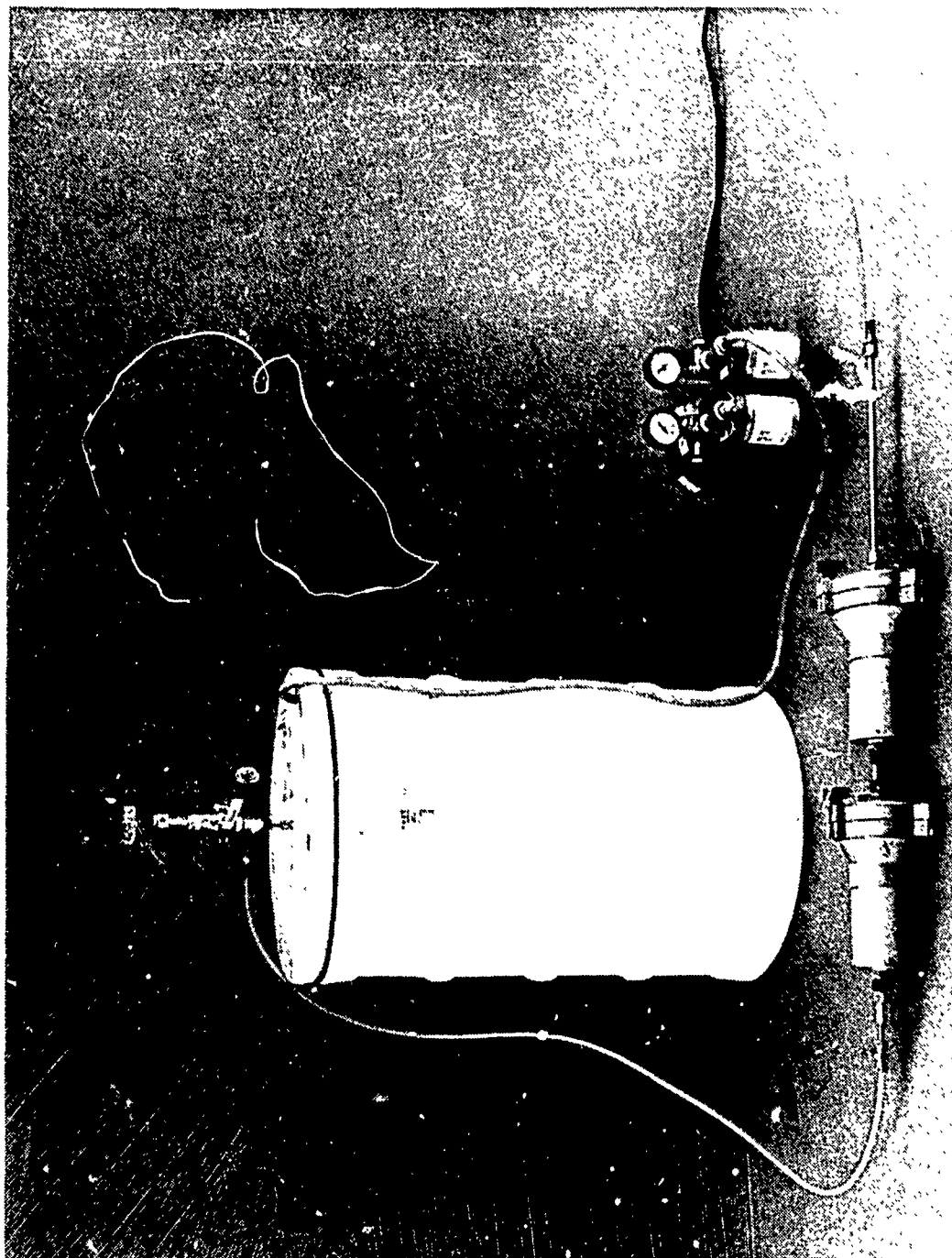


Figure 5. Experimental arrangement used to obtain breech gas combustion products from a 155 mm caliber gun for PAH analyses. The figure shows the breech adaptor, with a Teflon tube to extend through the breech block into the main combustion area. For further details see text.

the sampling line and the breech adaptor removed from the gun. The filters and polyurethane puffs were removed from the General Metal Work samplers and stored in glass containers purged with nitrogen for transport back to Chicago for analysis. The combustion gas in the Teflon bag was allowed to thoroughly mix for some ten minutes after collection and was then sampled into an evacuated metal flask. The flask was returned to Chicago for analysis of CO, CO₂, and H₂. Using the above combustion gas sampling volumes, no breakthrough from the first to the second GMW collector occurred. In most subsequent tests only one GMW collector was used. Due to the relatively large amount of gas required to be sampled for these analyses, no attempt was made to sample spent shell casings.

3.3.8 Combustion Product Sampling From A Bore Evacuator, 155 mm Gun

Some large bore guns are fitted with a device known as a bore evacuator, the purpose of which is to minimize the amount of gas escaping from the gun barrel when the breech is opened for removing the spent round and re-loading the weapon. They are most commonly used on vehicle-mounted guns to minimize crew exposures to gun smoke combustion products. The bore evacuator on a 155 mm caliber gun consists of an annular enclosure (volume ≈20 liters) mounted about half way along the gun barrel. Internal holes connect the evacuator's enclosed volume to that of the barrel. For the present study, a threaded hole (1/4" pipe thread) was tapped into the outer wall of the evacuator housing and a stainless steel valve installed. Gas samples from the evacuator volume were extracted through the valve after firing the round. Between firings, the gas in the evacuator was "blown out" with filtered compressed air. In the present study, it was hoped that gas samples extracted from the bore evacuator would undergo oxidation and simulate the effect of muzzle flash on the composition of the propellant combustion products.

3.4 SUMMARY OF GUN EMISSIONS SAMPLED

The gun emissions sampled during the course of the program are summarized in Table 3 together with the dates on which the guns were sampled. The original intent of the program was to obtain five individual samples of combustion products from a given weapon under the same conditions for each chemical analysis performed, together with necessary blanks and background samples. In

TABLE 3. GUN EMISSIONS SAMPLED IN PROGRAM FROM THE BREECH, SPENT CASINGS,
AND BORE EVACUATOR

Date Sampled	Sets of Samples Collected								
	Gun (Bore mm)	Breech					Spent Casing		
		Glass ^a Flask	PAH	Tenax	Particulate Metals	[S04]	Glass Flask	PAH	Tenax
April 28, 1988	120	- ^b	-	-	-	-	-	-	-
May 20, 1988	105	5	3	4	-	-	2	0 ^c	3
June 6, 1988 & June 7, 1988	25	5	1	5	-	-	2	0 ^d	2
June 22, 1988	105	0 ^c	4	0 ^c	-	-	3	0	3
June 23, 1988	25	0 ^c	2	0 ^c	-	-	2	0 ^d	2
August 9, 1988	120	5	5	5	5	-	0 ^e	0 ^e	0 ^e
October 4, 1988	155	5	3	0 ^b	5	3	0 ^e	0 ^e	0 ^e
March 4, 1989 March 7, 1989	155	5 ^f	0	0	0	0	0 ^e	0 ^e	0 ^e

^aOne set of glass flasks consisted of five separate flasks sampled simultaneously for content analyses of HCN, NH₃, H₂S, (NO_x + SO_x), and aldehydes.

^bPreliminary range finding studies.

^cSamples not collected due to sampling equipment limitations at the time.

^dTechnically not feasible to sample these emissions.

^eNo spent shell casing associated with these rounds.

^fOne set of glass flasks in this case consisted of three flasks sampled simultaneously for analyses of HCN, NH₃, and aldehydes.

practice, this was not always possible. There were a variety of reasons for this.

- Gun smoke samples were obtained by "piggy backing" on gun firing tests that were being made by "The Advanced System Division, Armament Advanced Technology Directorate, Aberdeen Proving Ground." Often, the number of rounds fired or the time available precluded the full number of samples being obtained.
- In a number of firings of the 105, 120 and 155 caliber weapons, the rounds were temperature conditioned to either 125°F or -35°F prior to firing. Because of the limited number of rounds fired, supposedly identical combustion product samples had to be taken from the rounds fired at different initial temperatures. It was not clear how this would affect the composition of the combustion products, though it was known that significantly different maximum tube pressures could result, i.e., for a 105 mm round at 125°F, $P_{max} = 72,000$ psi whereas at -35°F, $P_{max} = 48,000$ psi. Subsequent chemical analyses of the combustion products from rounds fired at different initial temperatures showed significant differences in composition.
- In some cases in which breech and spent casing emission were to be collected, sampling equipment limitations precluded the full number of samples being obtained.
- In the bore evacuator sampling attempts, a combination of technical problems associated with the gun ballistic monitoring equipment, mechanical problems with the vehicle and extremely adverse weather permitted only three rounds to be fired over a one week waiting period. Two of the rounds fired were temperature conditioned to 125°F, contained a granular propellant, and exhibited an extremely pronounced muzzle flash on firing. The third round was fired at ambient temperature ($\approx 35^\circ\text{F}$), contained a stick propellant and exhibited no muzzle flash at all. The presence and lack of muzzle flash may be indicative of significantly different chemistry in the two cases.

4. EXPERIMENTAL DATA AND COMPUTATION OF RESULTS

4.1 INTRODUCTION

During the course of the program a large amount of experimental data was accumulated. A substantial effort was required in organizing the data and in its reduction to the form desired. As noted earlier in the report, the experimentally determined combustion product concentrations have all been calculated in their final form with respect to the amount of carbon monoxide present in the combustion gas. Carbon monoxide was chosen as the reference gas for the reasons stated earlier.

The same data organizational and computational procedures were used on all weapons systems studied. A detailed description will not be made for each system. Rather, data obtained for the 120 mm caliber weapon will be presented in some detail as an example of the overall approach. For completeness, the corresponding data for the other weapons systems are presented in Appendix I. Features in the data unique to these systems compared to the 120 mm data will be noted following the latter's description in this section.

4.2 RESULTS AND COMPUTATIONS FOR 120 mm CALIBER XM256 GUN WITH ROUNDS CONTAINING JA2 PROPELLANT

4.2.1 Data Related Specifically to Inorganic Gases and Methane

The 120 mm caliber gun was used initially in limited range finding studies to establish the adequacy of the sampling procedures with respect to combustion product gas sample size. After the initial studies (04/28/88) a more complete analysis of this gun's combustion products was made (08/09/88). In Table 4, data are presented for all those samples on which GC analyses of inorganic gases and methane were made. For convenience the data are considered in three groups:

- (a) 1-liter glass flasks containing combustion gas samples for subsequent HCN, NH_3 , NO_x/SO_x , H_2S and aldehyde analyses, were always analyzed for inorganic gases and methane. Data for the initial studies on the 120 mm caliber gun are reported in Table 4 in the column marked GC Run Nos. 27 through 54. The individual samples are further identified

TABLE 4. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JAZ
- INORGANIC GASES AND METHANE ANALYSIS RAW DATA

GC Run No.	Analysis No.	Emissions Source	GC Peak Areas				
			CO2	H2	N2	CH4	CO
27	0506-001	CALGAS, CT2112	6.41E+06	1.04E+06	5.60E+07	*	1.32E+07
28	0428-01003	ROUND 1(A), H2S	9.99E+06	9.95E+05	3.36E+07	2.15E+06	2.25E+07
29	0428-01013	ROUND 1(B), H2S	9.60E+06	9.50E+05	3.44E+07	2.09E+06	2.17E+07
30	0428-02003	ROUND 2(A), H2S	1.25E+07	1.31E+06	2.50E+07	3.00E+06	3.13E+07
31	0428-02013	ROUND 2(B), H2S	1.14E+07	1.20E+06	2.84E+07	2.73E+06	2.86E+07
32	0428-06003	BACKGROUND, H2S	*	*	6.44E+07	*	*
33	0506-002	CALGAS, CT2112	6.92E+06	1.07E+06	5.35E+07	*	1.29E+07
34	0428-01001	ROUND 1(A), HCN	1.01E+07	9.98E+05	3.24E+07	2.22E+06	2.57E+07
35	0428-02001	ROUND 2(A), HCN	1.21E+07	1.27E+06	2.57E+07	2.93E+06	3.05E+07
36	0428-02011	ROUND 2(B), HCN	1.12E+07	1.09E+06	2.83E+07	2.69E+06	2.85E+07
37	0428-01011	ROUND 1(B), HCN	9.51E+06	9.71E+05	3.36E+07	2.09E+06	2.17E+07
38	0428-06001	BACKGROUND, HCN	*	*	6.30E+07	*	*
39	0506-003	CALGAS, CT2112	6.93E+06	1.05E+06	5.30E+07	*	1.28E+07
40	0428-01101	ROUND 1(A), HCN	1.01E+07	9.79E+05	3.22E+07	2.21E+06	2.57E+07
41	0506-004	CALGAS, CT2112	6.97E+06	1.07E+06	5.35E+07	2.70E+04	1.29E+07
42	0428-02002	ROUND 2(A), NH3	1.20E+07	1.16E+06	2.63E+07	2.87E+06	2.97E+07
43	0428-01012	ROUND 1(B), NH3	9.81E+06	9.49E+05	3.40E+07	2.10E+06	2.19E+07
44	0428-02012	ROUND 2(B), NH3	1.15E+07	1.07E+06	2.78E+07	2.71E+06	2.84E+07
45	0428-01002	ROUND 1(A), NH3	1.03E+07	9.73E+05	3.22E+07	2.21E+06	2.54E+07
46	0428-06002	BACKGROUND, NH3	*	*	6.33E+07	*	*
47	0506-005	CALGAS, CT2112	5.97E+06	1.16E+06	5.28E+07	*	1.28E+07
48	0509-001	CALGAS, CT2112	6.21E+06	1.08E+06	5.16E+07	*	1.22E+07
49	0428-01014	ROUND 1(B), NOx	7.37E+06	7.78E+05	2.69E+07	1.61E+06	1.68E+07
50	0428-01004	ROUND 1(A), NOx	9.36E+06	9.76E+05	3.00E+07	2.06E+06	2.13E+07
51	0428-02014	ROUND 2(B), NOx	1.09E+07	1.14E+06	2.72E+07	2.63E+06	2.78E+07
52	0428-02004	ROUND 2(A), NOx	1.19E+07	1.21E+06	2.39E+07	2.88E+06	3.02E+07
53	0428-06004	BACKGROUND, NOx	*	*	5.86E+07	*	*
54	0509-002	CALGAS, CT2112	6.79E+06	1.10E+06	5.19E+07	*	1.26E+07
55	0428-0502308	ROUND 5(B); SM.CAN, FUL.EVAC	8.76E+06	9.52E+05	3.35E+07	2.41E+06	2.16E+07
56	0428-0501309	ROUND 5(A); SM.CAN, 1/2 EVAC	2.46E+06	2.97E+05	5.28E+07	7.62E+05	6.89E+06

(REPEAT)

TABLE 4. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2
- INORGANIC GASES AND METHANE ANALYSIS RAW DATA (CONTINUED)

GC Run No.	Analysis No.	Emissions Source	GC Peak Areas				
			CO2	H ₂	N ₂	CH ₄	CO
57	0428-0504504	ROUND 5(D); LG CAN, FUL. EVAC	6.24E+06	5.85E+05	4.25E+07	1.61E+06	1.45E+07
58	0428-0503506	ROUND 5(C); LG CAN, 1/2 EVAC	5.31E+06	5.34E+05	4.54E+07	1.38E+06	1.23E+07
59	0428-0506513	BACKGROUND; LG CAN, FUL. EVAC	*	*	6.14E+07	*	*
60	0509-003	CALGAS, CT2112	6.91E+06	1.14E+06	5.23E+07	*	1.27E+07
61	0428-0300312	ROUND 3; SM. CAN, FUL. EVAC; (PAH)	9.20E+06	9.52E+05	3.37E+07	2.23E+06	2.11E+07
62	0428-0400316	ROUND 4; SM. CAN, FUL. EVAC; (PAH)	6.25E+06	6.58E+05	4.34E+07	1.62E+06	1.46E+07
63	0509-004	CALGAS, CT2112	6.89E+06	1.07E+06	5.16E+07	3.10E+04	1.25E+07
379	0907-101	CALGAS, CT2112	7.01E+06	1.23E+06	5.78E+07	2.84E+04	1.44E+07
380	0907-102	CALGAS, CT2112	6.83E+06	1.17E+06	5.71E+07	2.80E+04	1.37E+07
381	0907-103	CALGAS, CT2112	6.95E+06	1.20E+06	5.67E+07	*	1.41E+07
382	0907-104	CALGAS, CT2112	7.25E+06	1.26E+06	5.83E+07	2.87E+04	1.46E+07
383	0908-001	CALGAS, CT2112	*	1.29E+06	5.88E+07	2.89E+04	1.47E+07
384	0908-002	CALGAS, CT2112	7.33E+06	1.29E+06	5.86E+07	2.91E+04	1.48E+07
385	0908-003	CALGAS, CT2112	7.31E+06	1.28E+06	5.85E+07	2.88E+04	1.48E+07
386	080901-01001	RND 1 BREECH, HCN	4.47E+06	1.03E+06	4.76E+07	1.94E+06	1.70E+07
387	080901-01001	RND 1 BREECH, HCN (REPEAT)	4.41E+06	9.99E+05	4.70E+07	1.91E+06	1.67E+07
388	080902-02001	RND 2 BREECH, HCN	4.32E+06	9.78E+05	4.77E+07	2.20E+06	1.69E+07
389	080903-03001	RND 3 BREECH, HCN	4.27E+06	1.02E+06	4.78E+07	1.92E+06	1.70E+07
390	080904-04001	RND 4 BREECH, HCN	4.06E+06	1.01E+06	4.85E+07	1.84E+06	1.61E+07
391	080905-05001	RND 5 BREECH, HCN	4.98E+06	1.07E+06	4.51E+07	2.29E+06	1.90E+07
392	0809-06001	BACKGROUND, HCN	*	*	6.94E+07	*	*
393	080901-01002	RND 1 BREECH, NH3	4.88E+06	1.01E+06	4.74E+07	1.93E+06	1.68E+07
394	080902-02002	RND 2 BREECH, NH3	4.64E+06	9.69E+05	4.75E+07	2.16E+06	1.66E+07
395	0908-004	CALGAS, CT2112	7.20E+06	1.25E+06	5.79E+07	3.63E+04	1.45E+07
396	0908-005	CALGAS, CT2112	7.35E+06	1.28E+06	5.87E+07	2.99E+04	1.48E+07
397	080903-03002	RND 3 BREECH, NH3	4.76E+06	1.03E+06	4.79E+07	1.91E+06	1.70E+07
398	080904-04002	RND 4 BREECH, NH3	4.44E+06	1.01E+06	4.83E+07	1.82E+06	1.59E+07
399	080905-05002	RND 5 BREECH, NH3	5.39E+06	1.06E+06	4.52E+07	2.28E+06	1.90E+07

TABLE 4. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2
- INORGANIC GASES AND METHANE ANALYSIS RAW DATA (CONTINUED)

GC Run No.	Analysis No.	Emissions Source	GC Peak Areas				
			CO2	H2	N2	CH4	CO
400	0809-06002	BACKGROUND, NH3	5.52E+04	*	6.94E+07	*	6.31E+04
401	0908-006	CALGAS, CT2112	7.17E+06	1.25E+06	5.81E+07	2.99E+04	1.45E+07
402	080901-01003	RND 1 BREECH, H2S	4.90E+06	1.00E+06	4.77E+07	1.88E+06	1.64E+07
403	080902-02003	RND 2 BREECH, H2S	4.70E+06	9.56E+05	4.77E+07	2.14E+06	1.65E+07
404	080903-03003	RND 3 BREECH, H2S	4.75E+06	1.01E+06	4.75E+07	1.88E+06	1.67E+07
405	080904-04003	RND 4 BREECH, H2S	2.70E+06	5.79E+05	5.71E+07	1.06E+06	9.23E+06
406	080905-05003	RND 5 BREECH, H2S	5.40E+06	1.05E+06	4.50E+07	2.24E+06	1.87E+07
407	0809-06003	BACKGROUND, H2S	2.79E+04	*	6.91E+07	9.09E+03	7.15E+04
408	0908-007	CALGAS, CT2112	7.17E+06	1.25E+06	5.77E+07	3.02E+04	1.44E+07
409	0909-001	CALGAS, CT2112	(1.25E07)	1.27E+06	5.93E+07	3.00E+04	1.47E+07
410	0909-002	CALGAS, CT2112	7.32E+06	1.28E+06	5.87E+07	3.03E+04	1.47E+07
411	080901-01004	RND 1 BREECH, NOx	4.19E+06	9.29E+05	4.40E+07	1.73E+06	1.51E+07
412	080902-02004	RND 2 BREECH, NOx	4.09E+06	8.99E+05	4.44E+07	2.00E+06	1.53E+07
413	080903-03004	RND 3 BREECH, NOx	4.05E+06	9.34E+05	4.52E+07	1.74E+06	1.52E+07
414	080904-04004	RND 4 BREECH, NOx	3.86E+06	9.45E+05	4.59E+07	1.71E+06	1.49E+07
415	080905-05004	RND 5 BREECH, NOx	4.83E+06	1.01E+06	4.23E+07	2.14E+06	1.78E+07
416	0809-06004	BACKGROUND, NOx	*	*	5.76E+07	9.19E+03	7.55E+04
417	0909-003	CALGAS, CT2112	7.13E+06	1.23E+06	5.72E+07	3.04E+04	1.43E+07
418	080901-01005	RND 1 BREECH, ALD	4.43E+06	9.33E+05	4.38E+07	1.73E+06	1.52E+07
419	080902-02005	RND 2 BREECH, ALD	4.31E+06	8.79E+05	4.34E+07	1.94E+06	1.50E+07
420	0909-004	CALGAS, CT2112	7.22E+06	1.25E+06	5.81E+07	3.49E+04	1.46E+07
421	080903-03005	RND 3 BREECH, ALD	4.32E+06	9.39E+05	4.37E+07	1.71E+06	1.53E+07
422	080904-04005	RND 4 BREECH, ALD	4.09E+06	9.22E+05	4.46E+07	1.65E+06	1.44E+07
423	080905-05005	RND 5 BREECH, ALD	4.88E+06	9.83E+05	4.13E+07	2.07E+06	1.73E+07
424	0809-06005	BACKGROUND, ALD	2.96E+04	*	6.39E+07	*	4.37E+04
425	0909-005	CALGAS, CT2112	7.29E+06	1.26E+06	5.87E+07	3.06E+04	1.47E+07
426	0912-001	CALGAS, CT2112	(1.25E07)	1.25E+06	6.10E+07	2.94E+04	1.51E+07
427	0912-002	CALGAS, CT2112	7.54E+06	1.27E+06	6.03E+07	2.99E+04	1.51E+07
428	0912-003	CALGAS, CT2112	7.58E+06	1.28E+06	6.06E+07	3.05E+04	1.53E+07
429	080901-PC302	RND 1 BREECH, PAH	4.10E+06	8.33E+05	5.45E+07	1.92E+06	1.51E+07

TABLE 4. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2
- INORGANIC GASES AND METHANE ANALYSIS RAW DATA (CONTINUED)

GC Run No.	Analysis No.	Emissions Source	GC Peak Areas				
			CO2	H2	N2	CH4	CO
430	080902-PC303	RND 2 BREECH, PAH	4.70E+06	1.05E+06	5.11E+07	2.00E+06	1.80E+07
431	080904-PC304	RND 3 BREECH, PAH	3.37E+06	7.69E+05	5.69E+07	1.48E+06	1.30E+07
432	080905-PC305	RND 5 BREECH, PAH	4.37E+06	9.82E+05	5.18E+07	2.09E+06	1.77E+07
433	080906-PC307	RND 6 BREECH, PAH	3.93E+06	9.85E+05	5.29E+07	1.76E+06	1.64E+07
434	0912-004	CALGAS, CT2112	7.67E+06	1.29E+06	6.12E+07	3.17E+04	1.55E+07
435	080901-TC308	RND 1 BREECH, TENAX	4.37E+06	9.09E+05	5.35E+07	1.80E+06	1.58E+07
436	080902-TC310	RND 2 BREECH, TENAX	4.48E+06	9.56E+05	5.23E+07	2.14E+06	1.70E+07
437	080903-TC311	RND 3 BREECH, TENAX	4.21E+06	9.25E+05	5.30E+07	1.83E+06	1.61E+07
438	080905-TC312	RND 5 BREECH, TENAX	3.79E+06	9.35E+05	5.41E+07	1.73E+06	1.57E+07
439	080906-TC316	RND 6 BREECH, TENAX	4.64E+06	9.70E+05	5.04E+07	2.14E+06	1.82E+07
440	080908-TC318	BACKGROUND, TENAX	4.22E+05	9.68E+04	7.12E+07	2.05E+05	1.92E+06
441	0912-005	CALGAS, CT2112	7.54E+06	1.25E+06	6.06E+07	3.16E+04	1.53E+07
442	080908-TC318	BACKGROUND, TENAX (REPEAT)	4.13E+05	9.72E+04	7.17E+07	1.98E+05	1.87E+06

*Below Detection Limit (1.00E+02)

in the column headed Analysis No., in which the first four digits represent the date of sample acquisition (day/month). Also identified in the data are nine injections made for the GC calibration with a certified gas standard mixture listed as CALGAS Matheson Certified Standard under Emissions Source (Table 4). Under the same column, the designation ROUND 1A and 1B, indicates that two gas samples were obtained out of the breech from a single firing of round #1. The additional designations--H₂S, HCN, NH₃, and NO_x--under Emissions Source indicates that these samples were subsequently analyzed for these species.

- (b) Metal cylinders containing the combustion gas volume sampled through the Tenax collectors for subsequent GC/MS analyses were analyzed for inorganic gas and methane. These data are shown in GC Runs Nos. 55 through 59 in Table 4 taken during the initial range finding studies on the 120 mm caliber gun. Two sizes of metal cylinders were used in the range finding studies with volumes of 281 ml (SM, CAN) and 2154 ml (LG, CAN). To further vary the volume of gas sampled, the cylinders were used either fully evacuated (FULL EVAC) or contained air at half an atmosphere pressure (1/2 EVAC). These four combustion gas samples were all obtained from the firing of one round designated #5.
- (c) Metal cylinders (Vol. 281 ml) containing samples of the combustion gas drawn through the General Metal Works PAH samplers (30 liter in these experiments).

As a result of these initial studies on the 120 mm caliber gun, the volume of combustion gases to be sampled at ambient pressure through Tenax collectors for GC/MS analysis was established at 281 ml and was the volume of gas sampled in all subsequent studies. Similarly, based on these initial studies the volume of combustion gases to be sampled for PAH analyses was set in the range of 10 to 30 liters in all subsequent studies.

Data for the more complete analyses of inorganic gases and methane (08/09/88) in the 120 mm caliber gun combustion products are also presented in Table 4, GC Run Nos. 379 through 442.

In Table 5 the raw data from Table 4 have been re-arranged so that analytical data, volume % of inorganic gases and methane in the collected sample (includes these gases plus oxygen, water vapor, etc.) from a firing of the same round are arranged together for easy comparison of consistency. Thus, the composition of the inorganic gases and methane determined in four glass flasks, simultaneously sampled from Round #2A (GC run Nos. 35, 42, 30, and 52

TABLE 5. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2
- M120 INORGANIC GASES AND METHANE CONCENTRATIONS

GC Run No.	Sample No.	Emissions Source	Concentration (Vol %)			
			CO ₂	H ₂	N ₂	CH ₄
38	0428-06001	BACKGROUND, HCN	*	*	76.09	*
46	0428-06002	BACKGROUND, NH3	*	*	76.44	*
32	0428-06003	BACKGROUND, H2S	*	*	77.75	*
53	0428-06004	BACKGROUND, NOx	*	*	73.28	*
34	0428-01001	RND 1(A) BREECH, HCN	11.94	11.15	39.11	2.47
45	0428-01002	RND 1(A) BREECH, NH3	12.18	10.86	38.84	2.46
28	0428-01003	RND 1(A) BREECH, H2S	11.79	11.11	40.58	2.39
50	0428-01004	RND 1(A) BREECH, NOx	11.27	10.72	37.55	2.00
37	0428-01011	RND 1(B) BREECH, HCN	11.22	10.84	40.6	12.32
43	0428-01012	RND 1(B) BREECH, NH3	11.58	10.60	40.99	2.34
29	0428-01013	RND 1(B) BREECH, H2S	11.32	10.60	41.48	2.32
49	0428-01014	RND 1(B) BREECH, NOx	8.87	8.55	33.59	1.56
35	0428-02001	RND 2(A) BREECH, HCN	14.25	14.20	31.06	3.25
42	0428-02002	RND 2(A) BREECH, NH3	14.21	13.00	31.79	3.19
30	0428-02003	RND 2(A) BREECH, H2S	14.76	14.64	30.20	3.33
52	0428-02004	RND 2(A) BREECH, NOx	14.30	13.34	29.88	2.78
36	0428-02011	RND 2(B) BREECH, HCN	13.17	12.20	34.15	3.00
44	0428-02012	RND 2(B) BREECH, NH3	13.53	11.95	33.62	3.01
31	0428-02013	RND 2(B) BREECH, H2S	13.42	13.35	34.28	3.03
51	0428-02014	RND 2(B) BREECH, NOx	13.14	12.52	33.95	2.54
392	0809-06001	BACKGROUND, HCN	*	*	77.18	*
400	0809-06002	BACKGROUND, NH3	0.06	*	77.18	*
407	0809-06003	BACKGROUND, H2S	0.03	*	76.79	0.01
416	0809-06004	BACKGROUND, NOx	*	*	63.98	0.01
						0.08

TABLE 5. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2
- M120 INORGANIC GASES AND METHANE CONCENTRATIONS (CONTINUED)

GC Run No.	Sample No.	Emissions Source	Concentration (Vol %)			
			CO ₂	H ₂	N ₂	CH ₄
386	080901-01001	RND 1 BREECH, HCN	4.98	9.78	52.97	1.91
393	080901-01002	RND 1 BREECH, NH3	5.43	9.58	52.67	1.90
402	080901-01003	RND 1 BREECH, H2S	5.45	9.51	53.05	1.85
411	080901-01004	RND 1 BREECH, NOx	4.67	8.89	48.92	1.66
388	080902-02001	RND 2 BREECH, HCN	4.81	9.28	53.05	2.17
394	080902-02002	RND 2 BREECH, NH3	5.17	9.19	52.82	2.13
403	080902-02003	RND 2 BREECH, H2S	5.23	9.07	53.05	2.11
412	080902-02004	RND 2 BREECH, NOx	4.56	8.60	49.37	1.92
389	080903-03001	RND 3 BREECH, HCN	4.75	9.70	53.13	1.89
397	080903-03002	RND 3 BREECH, NH3	5.29	9.76	53.23	1.88
404	080903-03003	RND 3 BREECH, H2S	5.29	9.61	52.82	1.86
413	080903-03004	RND 3 BREECH, NOx	4.51	8.95	50.26	1.67
390	080904-04001	RND 4 BREECH, HCN	4.52	9.54	53.94	1.82
398	080904-04002	RND 4 BREECH, NH3	4.94	9.56	53.74	1.80
405	080904-04003	RND 4 BREECH, H2S	3.01	5.49	63.54	1.04
414	080904-04004	RND 4 BREECH, NOx	4.30	9.05	51.00	1.64
391	080905-05001	RND 5 BREECH, HCN	5.54	10.11	50.18	2.26
399	080905-05002	RND 5 BREECH, NH3	6.00	10.09	50.30	2.25
406	080905-05003	RND 5 BREECH, H2S	6.00	9.99	50.03	2.20
415	080905-05004	RND 5 BREECH, NOx	5.38	9.69	46.99	2.05

* = Below Detection Limit

[Table 5]), are in close agreement as anticipated. Similar behavior is shown in most of the other groupings. There are clearly some exceptions. Thus in the group, GC Run Nos. 37, 43, 29 and 49, the concentrations (Vol %) of the analyzed gases found in flask #49 are clearly lower than those found in the other three flasks sampling the same combustion gas. It is possible that the valve on flask #49 was not fully opened when the sample was taken resulting in a gas volume being collected at less than atmospheric pressure. However, since the final analytical results are reported in terms of species concentration relative to unit concentration of CO, the data are not compromised. There is also a marked difference in the inorganic gases and methane concentrations determined in the initial sampling experiments (04/28/88) and those determined later (08/09/88). This in part could be due to differing amounts of dilution air entering the gun barrel during the two sampling processes. Another contributing factor may be related to the nature of the projectile. In the initial tests, the projectile was of conventional "bullet shape", whereas in the later series of tests the projectile (heavier and blunt) was designed to deliberately produce maximum gun recoil (high impulse) with the object of "proofing" new barrels prior to their installation in tanks.

4.2.2 Raw Data Sets for Analytically Determined

CN⁻, NH₃, S⁼, SO_x, and NO_x

Combustion gases collected in the 1-liter glass flask were analyzed initially for their CO, CO₂, H₂, N₂ and CH₄ content using gas chromatography and the data assembled as described in 4.2.1. After these analyses the solutions in these flasks were removed and analyzed for the above titled species. According to TEI control or spiked samples (EPA certified solutions) were made during these analyses to confirm integrity of the reported data. The resulting analytical data are presented in Tables 6 through 9. Cyanide and ammonia samples were analyzed by TEI of Niles, Illinois, and the results quoted in terms of concentration of the species determined in a 50-ml sample volume. Sulfide ion was analyzed at IITRI and results reported as total S⁼ in the sample. Similarly, SO_x and NO_x were determined at IITRI in terms of the mass of SO₄⁼ and NO₃⁼ contained in a 1-liter gas sample. These data were then all converted to micrograms of analyte per liter of collected sample and combined with analogous data for the CO associated with each sample, Table 10.

TABLE 6. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM;
PROPELLANT, JA2 - HCN ANALYSIS RAW DATA

Sample No.	Emission Source	Total ⁽¹⁾ Cyanide (mg/L)
0428-01001[A]	BREECH	18.3
0428-01001[B]	BREECH	12.3
0428-02001[A]	BREECH	23.8
0428-02001[B]	BREECH	18.9
0428-06001	BACKGROUND	*
0809-01001	BREECH	12.4
0809-02001	BREECH	23.5
0809-03001	BREECH	9.82
0809-04001	BREECH	12.5
0809-05001	BREECH	14.8
0809-06001	BACKGROUND	*
0809-11001	STANDARD, 0.302 mg/L (a)	0.29
0809-12001	STANDARD, 3.02 mg/L	3.31
0809-13001	STANDARD, 15.11 mg/L	16.7

(1) SOLUTION VOLUME = 50 mL

* = BELOW DETECTION LIMIT (0.1 mg/L)

(a) CONTROL SAMPLES

TABLE 7. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM;
PROPELLANT, JA2 - NH3 ANALYSIS RAW DATA

Sample No.	Emission Source	Total ⁽¹⁾ Ammonia (mg/L)
0428-01002[A]	BREECH	25.6
0428-01002[B]	BREECH	27.2
0428-020021[A]	BREECH	32.2
0428-020021[B]	BREECH	37.8
0428-06002	BACKGROUND	*
0809-01002	BREECH	100
0809-02002	BREECH	109
0809-03002	BREECH	104
0809-04002	BREECH	103
0809-05002	BREECH	116
0809-06002	BACKGROUND	0.16
0809-11002	STANDARD, 2.42 mg/L (a)	2
0809-12002	STANDARD, 9.66 mg/L	7.64
0809-13002	STANDARD, 48.3 mg/L	34.1

(1) SOLUTION VOLUME = 50 mL

* = BELOW DETECTION LIMIT (0.1 mg/L)

(a) CONTROL SAMPLES

**TABLE 8. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256;
BORE, 120 MM; PROPELLANT, JA2- H2S ANALYSIS RAW DATA**

Sample No.	Emission Source	S ²⁻ (from H ₂ S) (micrograms)
0809-01003	BREECH	34.2
0809-02003	BREECH	121.1
0809-03003	BREECH	33.2
0809-04003	BREECH	27.3
0809-05003	BREECH	74.2
0809-06003	BACKGROUND	*

* = BELOW DETECTION LIMIT (0.4 micrograms)

**TABLE 9. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256;
BORE, 120 MM; PROPELLANT, JA2, - NOX AND SOX
ANALYSIS RAW DATA**

Analysis No.	Emissions Source	Sample Source	Total Sample ⁽¹⁾ Concentration (microgram/L Air)	
			NO ₃ ⁻	SO ₄ ²⁻
0719-02	0428-01004, RND 1	BREECH	79.5	1096.0
0719-04	0428-03004, RND 2	BREECH	80.9	1271.1
0719-08	0428-04004, RND 2	BREECH	70.1	1077.3
0719-09	0428-06004, BACKGROUND	BKGD	8.1	10.7
1026-07	0808-01004, RND 2	BREECH	175.5	560.4
1026-08	0809-02004, RND 4	BREECH	271.3	1144.4
1026-09	0809-03004, RND 6	BREECH	122.9	288.0
1026-10	0809-04004, RND 8	BREECH	167.6	336.6
1026-11	0809-05004, RND 9	BREECH	242.6	731.1
1026-12	0809-06004, BACKGROUND	BKGD	14.4	11.0

⁽¹⁾ DETECTION LIMIT - NO₃⁻ = 0.1 micrograms/L AIR
- SO₄²⁻ = 0.1 micrograms/L AIR

TABLE 10. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2
- MASS CONCENTRATION OF INORGANIC GAS EMISSIONS

GC Run No.	Sample No.	Emissions Source	Volume (ml)	Mass Concentration of Gases (Micrograms/Liter)					
				CO	HCN	NH ₃	H ₂ S	NO ₃ ⁻	SO ₄ ²⁻
38	0428-06001	BACKGROUND, HCN	1024	*	2				
46	0428-06002	BACKGROUND, NH ₃	1024	*		2			
42	0428-06003	BACKGROUND, H ₂ S	1024	*			!		
53	0428-06004	BACKGROUND, NO _x	1024	*				8	10
34	0428-01001	RND 1(A) BREECH, HCN	1024	348,328	928				
45	0428-01002	RND 1(A) BREECH, NH ₃	1024	344,696		1,520			
28	0428-01003	RND 1(A) BREECH, H ₂ S	1024	304,782			!		
50	0428-01004	RND 1(A) BREECH, NO _x	1024	298,382				78	1,070
37	0428-01011	RND 1(B) BREECH, HCN	1024	294,563	624				
43	0428-01012	RND 1(B) BREECH, NH ₃	1024	296,460		1,615			
29	0428-01013	RND 1(B) BREECH, H ₂ S	1024	293,980			!		
49	0428-01014	RND 1(B) BREECH, NO _x	1024	235,312				!	!
35	0428-02001	RND 2(A) BREECH, HCN	1024	413,030	1,207				
42	0428-02002	RND 2(A) BREECH, NH ₃	1024	403,191		1,912			
30	0428-02003	RND 2(A) BREECH, H ₂ S	1024	424,415			!		
52	0428-02004	RND 2(A) BREECH, NO _x	1024	422,745				79	1,241

TABLE 10. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2
- MASS CONCENTRATION OF INORGANIC GAS EMISSIONS (CONTINUED)

GC Run No.	Sample No.	Emissions Source	Volume (ml)	Mass Concentration of Gases (Micrograms/Liter)					
				CO	HCN	NH ₃	H ₂ S	NO ₃ ⁻	SO ₄ ²⁻
36	0428-02011	RND 2(B) BREECH, HCN	1024	385,992	960				
44	0428-02012	RND 2(B) BREECH, NH ₃	1024	384,731		2,244			
31	0428-02013	RND 2(B) BREECH, H ₂ S	1024	387,537			!		
51	0428-02014	RND 2(B) BREECH, NO _x	1024	389,021				68	1,052
392	0809-06001	BACKGROUND, HCN	1024	*	5				
400	0809-06002	BACKGROUND, NH ₃	1024	753		9			
407	0809-06003	BACKGROUND, H ₂ S	1024	854			*		
416	0809-06004	BACKGROUND, NO _x	1024	907				14	11
386	080901-01001	RND 1 BREECH, HCN	1024	202,353	629				
393	080901-01002	RND 1 BREECH, NH ₃	1024	200,980		5,937			
402	080901-01003	RND 1 BREECH, H ₂ S	1024	196,288			36		
411	080901-01004	RND 1 BREECH, NO _x	1024	180,977				171	547
388	080902-02001	RND 2 BREECH, HCN	1024	201,326	1,192				
394	080902-02002	RND 2 BREECH, NH ₃	1024	197,673		6,471			
403	080902-02003	RND 2 BREECH, H ₂ S	1024	196,599			129		
412	080902-02004	RND 2 BREECH, NO _x	1024	183,391				265	1,118

TABLE 10. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2
- MASS CONCENTRATION OF INORGANIC GAS EMISSIONS (CONTINUED)

GC Run No.	Sample No.	Emissions	Volume (ml)	Mass Concentration of Gases (Micrograms/Liter)						
				CO	HCN	NH ₃	H ₂ S	NO ₃ ⁻	SO ₄ ²⁻	
389	080903-03001	RND 3 BREECH, NO _x	1024	202,591	498					
397	080903-03002	RND 3 BREECH, NH ₃	1024	202,436		6,175				
404	080903-03003	RND 3 BREECH, H ₂ S	1024	198,807			35			
413	080903-03004	RND 3 BREECH, NO _x	1024	183,151				120		281
390	080904-04001	RND 4 BREECH, HCN	1024	192,433	751					
398	080904-04002	RND 4 BREECH, NH ₃	1024	190,141		6,887				
405	080904-04003	RND 4 BREECH, H ₂ S	1024	110,144			29			
414	080904-04004	RND 4 BREECH, NO _x	1024	178,262				164		329
391	080905-05001	RND 5 BREECH, HCN	1024	227,230	634					
399	080905-05002	RND 5 BREECH, NH ₃	1024	226,729		5,115				
406	080905-05003	RND 5 BREECH, H ₂ S	1024	223,124			79			
415	080905-05004	RND 5 BREECH, NO _x	1024	213,310				237		714

* = Below Detection Limit

! = Sample Collected; Analysis Failed

CONTROL SAMPLES

4.2.3 Final Data Compilation for Inorganic Gases and Methane Relative to Carbon Monoxide (Moles/Mole) Present in the Combustion Products

In Table 11 the data for the inorganic gases and methane are presented in their final form in terms of moles of species per mole of carbon monoxide in the combustion products. The table contains data derived for each species separately and average values. On examination of the data in Table 11 it is clear that the analytical results obtained on 04/28/89 were not in good agreement with those obtained on 8/09/89. For this reason, two separate averages were computed for these data.

4.2.4 Raw and Final Data Sets for PAH Analyses

Data are presented in Table 12 from the analyses of PAHs in combustion product gases in terms of mass concentration of a given PAH per liter of combustion gas sampled. In the initial tests on 04/28/89, this volume was set at 30 liters whereas in the second series of tests a volume of 20 liters was used. Under the heading Emissions Source in Table 12 for rounds 3 and 4 sampled on 04/28/89, the abbreviation SM, FULL EVAC is used. This indicates that the metal cylinder used to obtain a sample of the collected combustion gas for subsequent CO analyses had a volume of 281 ml and was fully evacuated prior to obtaining the sample. This designation was used to differentiate the different metal cylinder sampling volumes used in the initial range finding studies. In all subsequent studies, only one sampling volume was used, the small metal cylinder fully evacuated. Hence, it was not necessary to indicate this in future data compilations.

Data are presented in Table 13 giving the final results in terms of moles of PAH per mole of carbon monoxide in the combustion gases. In deriving these data corrections were made for the background PAH concentrations. In some cases, this resulted in negative values for the ratios. Examination of these results shows that PAH concentrations relative to carbon monoxide were approximately two orders of magnitude greater in the tests on 04/28/89 than those reported in the tests of 08/09/89.

TABLE 11. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2,
- MOLE OF INORGANIC GASES AND METHANE PER MOLE OF CARBON MONOXIDE

GC Run No.	Sample No.	Emissions Source	Moles of Species Per Moles of Carbon Monoxide (1)								
			CO ₂	H ₂	CH ₄	HCN	NH ₃	H ₂ S	NO ₃ ⁻	SO ₄ ²⁻	
34	0428-01001	RND 1(A) BREECH, HCN				0.0028					
45	0428-01002	RND 1(A) BREECH, NH ₃					0.0072				
28	0428-01003	RND 1(A) BREECH, H ₂ S						!			
50	0428-01004	RND 1(A) BREECH, NO ^x							0.00011		0.0010
		RND 1(A) BREECH,AVG ^x	0.426	0.397	0.084						
37	0428-01011	RND 1(B) BREECH, HCN				0.0022					
43	0428-01012	RND 1(B) BREECH, NH ₃					0.0089				
29	0428-01013	RND 1(B) BREECH, H ₂ S						!			
49	0428-01014	RND 1(B) BREECH, NO ^x							!		!
		RND 1(B) BREECH,AVG ^x	0.448	0.423	0.088						
35	0428-02001	RND 2(A) BREECH, HCN				0.0030					
42	0428-02002	RND 2(A) BREECH, NH ₃					0.0078				
30	0428-02003	RND 2(A) BREECH, H ₂ S						!			
52	0428-02004	RND 2(A) BREECH, NO ^x							0.00008		0.0008
		RND 2(A) BREECH,AVG ^x	0.404	0.387	0.088						
36	0428-02011	RND 2(B) BREECH, HCN				0.0026					
44	0428-02012	RND 2(B) BREECH, NH ₃					0.0096				
31	0428-02013	RND 2(B) BREECH, H ₂ S						!			
51	0428-02014	RND 2(B) BREECH, NO ^x							0.00007		0.0008
		RND 2(B) BREECH, AVG ^x	0.402	0.377	0.087						
386	080901-01001	RND 1 BREECH, HCN				0.0032					
393	080901-01002	RND 1 BREECH, NH ₃					0.0487				
402	080901-01003	RND 1 BREECH, H ₂ S						0.00015			
411	080901-01004	RND 1 BREECH, NO ^x							0.00039		0.0009
		RND 2(B) BREECH,AVG ^x	0.307	0.565	0.109						
388	080902-02001	RND 2 BREECH, HCN				0.0061					
394	080902-02002	RND 2 BREECH, NH ₃					0.0540				
403	080902-02003	RND 2 BREECH, H ₂ S						0.00054			
412	080902-02004	RND 2 BREECH, NO ^x									
		RND 2(B) BREECH, AVG ^x	0.296	0.542	0.125				0.00062		0.0018

TABLE 11. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2,
- MOLE OF INORGANIC GASES AND METHANE PER MOLE OF CARBON MONOXIDE (CONTINUED)

GC Run No.	Sample No.	Emissions Source	Moles of Species Per Moles of Carbon Monoxide (1)							
			CO ₂	H ₂	CH ₄	HCN	NH ₃	H ₂ S	NO ₃ ⁻	SO ₄ ²⁻
389	080903-03001	RND 3 BREECH, HCN				0.0025				
397	080903-03002	RND 3 BREECH, NH ₃					0.0503			
404	080903-03003	RND 3 BREECH, H ₂ S						0.00015		
413	080903-03004	RND 3 BREECH, NO							0.00026	0.0004
		RND 3 BREECH, AVG	0.294	0.56	40.108					
390	080904-04001	RND 4 BREECH, HCN				0.0040				
398	080904-04002	RND 4 BREECH, NH ₃					0.0597			
405	080904-04003	RND 4 BREECH, H ₂ S						0.00022		
414	080904-04004	RND 4 BREECH, NO							0.00038	0.0005
		RND 4 BREECH, AVG	0.294	0.585	0.110					
391	080905-05001	RND 5 BREECH, HCN				0.0029				
399	080905-05002	RND 5 BREECH, NH ₃					0.0444			
406	080905-05003	RND 5 BREECH, H ₂ S						0.00029		
415	080905-05004	RND 5 BREECH, NO							0.00047	0.0010
		RND 5 BREECH, AVG	0.301	0.523	0.115					
	BREECH	4/28/88 AVG (4) RSD	4.20E-01 0.045	3.96E-01 0.043	8.70E-02 0.133	2.63E-03 0.127	8.39E-03 0.110	!	6.30E-05 0.615	6.66E-04 0.594
	BREECH	8/09/88 AVG (5) RSD	2.98E-01 0.016	5.56E-01 0.038	1.13E-01 0.054	3.74E-03 0.343	5.14E-02 0.100	2.70E-04 0.537	4.27E-04 0.277	9.12E-04 0.519

! = Sample Collected; Analysis Failed

* = Below Detection Limit

TABLE 12. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2 - PAH ANALYSIS RAW DATA

ANALYSIS NO.	EMISSIONS SOURCE	SAMPLE VOLUME (LITERS)	MASS CONCENTRATION OF PAH IN COLLECTED SAMPLES (Micrograms/Liter)									
			PHEN-ANTHRENE	ANTHRACENE	FLUOR-ANTHENE	PYRENE	BENZ-a-ANTHRACENE	CHRYSENE	BENZ-b-FLUORANTHENE	BENZ-k-FLUORANTHENE	BENZ-a-PYRENE	BENZ-gt-PERYLENE
0428-0300-312	ROUND 3-SM, FUL-EVAC; (PAH)	30	3.71E-01	4.03E-02	1.53E-01	6.90E-01	9.48E-02	8.13E-02	1.87E-01	3.92E-02	3.85E-01	1.16E+00
0428-0400-316	ROUND 4-SM, FUL-EVAC; (PAH)	30	1.39E-01	1.29E-02	3.62E-02	2.41E-01	3.74E-02	8.90E-03	3.86E-02	7.80E-03	7.99E-02	3.74E-01
0428-0600-13	BACKGROUND, PAH	30	1.12E-02	3.35E-07	1.53E-04	4.53E-04	1.40E-04	1.07E-04	7.63E-05	4.23E-05	4.20E-05	9.33E-05
0428-15	BLANK, PAH	0	6.37E-04	*	*	*	2.30E-04	4.00E-05	2.40E-04	7.67E-05	6.33E-05	1.87E-04
0428-15	BLANK, PAH	0	*	*	3.67E-04	2.00E-04	3.47E-04	*	*	1.80E-06	1.80E-05	1.42E-05
0428-00	METHOD BLANK	0	*	*	*	*	1.53E-04	*	5.10E-05	1.77E-05	2.40E-05	4.33E-05
0809-02-PC302(A)	RND 2 BREECH, PAH	20	2.02E-03	*	1.38E-03	1.37E-02	1.90E-03	2.80E-03	4.04E-03	1.91E-02	5.29E-02	4.57E-01
0809-02-PC302(B)	RND 2 BREECH, PAH	20	*	*	*	*	*	*	6.30E-03	2.69E-02	6.41E-02	7.03E-01
0809-03-PC303	RND 3 BREECH, PAH	20	*	*	1.30E-03	1.30E-02	1.23E-03	1.25E-03	1.63E-03	7.10E-03	1.73E-02	3.54E-01
0809-04-PC304	RND 4 BREECH, PAH	20	5.75E-03	*	2.16E-03	2.00E-02	2.34E-03	3.55E-03	3.59E-03	2.43E-02	4.62E-02	5.86E-01
0809-05-PC305	RND 5 BREECH, PAH	20	1.43E-03	*	1.91E-03	1.37E-02	2.01E-03	2.76E-03	5.20E-03	2.50E-02	6.40E-02	6.19E-01
0809-06-PC307	RND 6 BREECH, PAH	20	9.90E-03	*	2.64E-03	5.75E-03	2.61E-03	3.74E-03	3.85E-03	1.52E-02	3.68E-02	3.84E-01
0809-09	BACKGROUND, PAH	20	1.85E-03	*	7.65E-04	8.65E-04	*	1.10E-04	2.30E-04	1.40E-04	3.05E-04	8.50E-05
0809-10	BLANK, PAH	0	*	*	*	*	*	*	*	*	*	*

* = Below Detection Limit; Variously, 1E-04 TO 5E-03 micrograms/L. See Text.

TABLE 13. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JAZ
- MOLES OF PAH PER MOLE OF CARBON MONOXIDE

ANALYSIS NO.	EMISSIONS SOURCE	MOLES OF PAH SPECIES PER MOLE OF CARBON MONOXIDE (1)									
		PHEN- ANTHRENE	FLUOR- ANTHRENE	ANTHRACENE	PYRENE	BENZ-3- ANTHRACENE	CHRYSENE	BENZ-D- FLUORANTHENE	BENZ-K- FLUORANTHENE	BENZ-A- PYRENE	BENZ-GH- PERYLENE
04280300-312	RND 3;SM,FUL.EVAC;(PAH)	2.85E-07	3.19E-08	1.07E-07	4.81E-07	5.85E-08	5.02E-08	1.03E-07	2.19E-08	2.15E-07	5.94E-07
04280400-316	RND 4;SM,FUL.EVAC;(PAH)	1.46E-07	1.48E-08	3.65E-08	2.44E-07	3.34E-08	7.88E-09	3.11E-08	6.26E-09	6.47E-08	2.76E-07
080902-PC302(A)	RND 2 BREECH, PAH	1.74E-10	*	5.19E-10	1.09E-08	1.43E-09	2.02E-09	2.60E-09	1.29E-08	3.58E-08	2.84E-07
080902-PC302(B)	RND 2 BREECH, PAH	-1.49E-09	*	-5.45E-10	-6.17E-10	*	-6.95E-11	3.47E-09	1.53E-08	3.64E-08	3.67E-07
080903-PC303	RND 3 BREECH, PAH	-1.49E-09	*	3.81E-10	8.65E-09	7.77E-10	7.17E-10	8.00E-10	3.98E-09	9.68E-09	1.85E-07
080904-PC304	RND 4 BREECH, PAH	4.38E-09	*	1.37E-09	1.89E-08	2.05E-09	3.01E-09	2.68E-09	1.91E-08	3.64E-08	4.24E-07
080905-PC305	RND 5 BREECH, PAH	-3.46E-10	*	8.27E-10	9.28E-09	1.30E-09	1.70E-09	2.89E-09	1.45E-08	3.71E-08	3.29E-07
080906-PC307	RND 6 BREECH, PAH	7.14E-09	*	1.46E-09	3.82E-09	1.80E-09	2.51E-09	2.27E-09	9.46E-09	2.28E-08	2.19E-07
BREECH 8/09/88 AVG (6)		1.39E-09	*	6.70E-10	8.49E-09	1.23E-09	1.65E-09	2.45E-09	1.25E-08	2.97E-08	3.01E-07
RSD		2.548		1.104	0.782	0.606	0.695	0.368	0.418	0.378	0.274

(1) LESS BACKGROUND LEVELS; (-) RATIOS REFLECT CONCENTRATIONS WHICH WERE LESS THAN BACKGROUND

* = BELOW DETECTION LIMIT

4.2.5 Raw and Final Data Sets for Aldehyde Analyses

Aldehyde analyses were made on combustion gases sampled into 1-liter glass flasks. Data are presented in terms of aldehyde mass per liter of combustion gas sampled, Table 14. In the initial tests on 04/28/89, background levels of the aldehydes appeared to be quite low compared to those found in the combustion products sampled. In the tests reported for 08/09/89, background aldehyde levels were comparable to or greater than those found in the combustion product samples in a number of cases. The reason for this is not known. As indicated in Table 14, Analysis No. 1-4 was repeated a second time with addition of specific aldehyde derivatives to the combustion product sample solution. Satisfactory recoveries were obtained for some aldehydes as indicated, but for crotonaldehyde and isobutyl aldehyde the results indicated recoveries of 200% and 163%, respectively, a disturbing finding.

Because of the above difficulties in the final data compilation, Table 15, the results have not been corrected for background aldehyde concentration levels.

4.2.6 Raw and Final Data Sets for Selected Volatile Organics, Tenax GC/MS Analysis

Raw data for combustion products sampled on Tenax collectors and analyzed by GC/MS are presented in Table 16 in terms of the total mass of given species on the Tenax collector. From the initial tests on 04/28/89, the volume of combustion gas to be sampled was established at 281 ml, and this sample volume was used in all subsequent tests. Under the column heading Round No., (Table 16), the abbreviations [FT] and [BK] are used. This indicates that two Tenax collectors mounted in series were used in sampling the combustion gas and that each was subsequently analyzed for its volatile organic content. The results indicate that for most of the species quantified, breakthrough from the front to the back Tenax collector was acceptably low. Unless otherwise stated, only one Tenax collector was used when sampling for volatile organics. Similarly, background and blank levels of the volatile organics were low compared to those found in the combustion product samples. Data in Table 17 are presented in terms of micrograms of analyte per liter of combustion gas sampled. In compiling the final data in Table 18, corrections have been made for the blank and background levels to obtain the final result in terms of moles of volatile

TABLE 14. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2
- ALDEHYDE ANALYSIS RAW DATA

ANALYSIS NO.	SAMPLE NO.	EMISSIONS SOURCE	MASS CONCENTRATION OF ALDEHYDES (1) (micrograms/Liter)							
			FORM-ALDEHYDE	ACET-ALDEHYDE	ACROLEIN/ACETONE(a)	PROPION-ALDEHYDE	CROTON-ALDEHYDE	ISOBUTYL-ALDEHYDE	BENZ-ALDEHYDE	HEXAN-ALDEHYDE
1-1	0428-01005	ROUND 1[A], BREECH	*	2.49	15.23	0.92	0.84	6.76	0.81	0.62
1-2	0428-02005	ROUND 1[B], BREECH	*	2.13	14.75	0.78	0.73	6.95	0.78	0.41
1-3	0428-03005	ROUND 2[A], BREECH	*	0.82	17.77	0.35	0.69	7.48	0.34	0.35
1-4 (2)	0428-04005	ROUND 2[B], BREECH	*	0.43	9.23	0.07	0.14	4.70	0.19	0.01
1-6	0428-06005	BACKGROUND	*	0.54	0.92	0.06	*	0.08	0.06	0.14
5-AID1	0809-01005	ROUND 2, BREECH	0.10	5.05	10.35	0.25	*	2.53	2.79	0.14
5-AID2	0809-02005	ROUND 4, BREECH	0.20	2.46	7.08	0.12	*	0.78	2.35	0.14
5-AID3	0809-03005	ROUND 6, BREECH	0.16	4.72	8.92	0.21	*	2.50	3.14	0.29
5-AID4	0809-04005	ROUND 9, BREECH	0.16	3.54	5.72	0.18	*	2.36	3.29	0.10
5-AID5	0809-05005	ROUND 11, BREECH	0.15	2.79	7.67	0.21	*	3.30	2.63	0.28
5-AID6	0809-06005	BACKGROUND	0.17	3.39	8.18	0.06	*	8.81	0.06	0.16

(1) COLLECTED SAMPLE VOLUME = 1024 ML/EACH

(2) ANALYSIS NO. 1-4: ALDEHYDE SPIKED RESULTS SHOW ACETYLALDEHYDE, ACROLOIN/ACETONE, BENZALDEHYDE RECOVERY OF 100% +/- 5%; CROTONALDEHYDE, 200%; ISOBUTYLALDEHYDE, 163%; FORMALDEHYDE, HEXONAL, AND PROPONAL LEVELS ARE TOO LOW TO EVALUATE.

* = BELOW DETECTION LIMIT (0.01 micrograms/L)

(a) BOTH MATERIALS ELUTE AT SAME TIME.

TABLE 15. COMBUSTION PRODUCT DATA EXAPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2
- RATIO OF ALDEHYDE CONCENTRATION TO CARBON MONOXIDE CONCENTRATION

ANALYSIS NO.	SAMPLE NO.	SOURCE	MOLES OF ALDEHYDE PER MOLE OF CARBON MONOXIDE (1)									
			FORM-ALDEHYDE	ACET-ALDEHYDE	ACROLEIN/ACETONE	PROPTON-ALDEHYDE	CROTON-ALDEHYDE	ISOBUTYL-ALDEHYDE	BENZ-ALDEHYDE	HEXAN-ALDEHYDE		
1-1	0428-01005	ROUND 1(A), BREECH	*	2.35E-07	1.09E-06	6.58E-08	5.01E-08	3.85E-07	3.16E-08	2.56E-08		
1-2	0428-02005	ROUND 1(B), BREECH	*	2.33E-07	1.23E-06	6.45E-08	5.01E-08	4.59E-07	3.54E-08	1.99E-08		
1-3	0428-03005	ROUND 2(A), BREECH	*	6.75E-08	1.11E-06	2.18E-08	3.59E-08	3.71E-07	1.17E-08	1.28E-08		
1-4	0428-04005	ROUND 2(B), BREECH	*	3.83E-08	6.19E-07	4.78E-09	*	2.50E-07	6.85E-09	*		
5-AID1	0809-01005	ROUND 2, BREECH	5.53E-08	1.93E-06	3.00E-06	7.14E-08	*	5.83E-07	4.43E-07	2.28E-08		
5-AID2	0809-02005	ROUND 4, BREECH	1.13E-07	9.37E-07	2.05E-06	3.58E-08	*	1.79E-07	3.72E-07	2.36E-08		
5-AID3	0809-03005	ROUND 6, BREECH	9.06E-08	1.80E-06	2.58E-06	6.01E-08	*	5.74E-07	4.97E-07	4.84E-08		
5-AID4	0809-04005	ROUND 9, BREECH	9.86E-08	1.45E-06	1.78E-06	5.52E-08	*	5.84E-07	5.60E-07	1.75E-08		
5-AID5	0809-05005	ROUND 11, BREECH	7.57E-08	9.53E-07	1.98E-06	5.56E-08	*	6.79E-07	3.72E-07	4.13E-08		
BREECH 04/28/88			*	1.44E-07	1.01E-06	3.92E-08	4.54E-08	3.66E-07	2.14E-08	1.94E-08		
RSD				0.734	0.265	0.784	0.181	0.236	0.664	0.329		
BREECH 08/09/88			8.66E-08	1.41E-06	2.28E-06	5.56E-08	*	5.20E-07	4.49E-07	3.07E-08		
RSD			0.255	0.327	0.220	0.231		0.376	0.181	0.434		

(1) BACKGROUND NOT SUBTRACTED FROM ALDEHYDE LEVELS.

* = BELOW ANALYSIS LIMITS

TABLE 16. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JAZ
- VOLATILE ORGANIC GASES, GC/MS RAW DATA

ANALYSIS NO.	SAMPLE NO.	EMISSION SOURCE	ROUND NO.	SAMPLE VOLUME (LITER)	COLLECTED VOLATILE ORGANIC GASES (micrograms)									
					ACRYLO-ETHYL					CYANO-				
					BENZENE	NITRILE	BENZENE	TOLUENE	PYRIDINE	STYRENE	BENZENE	NAPHTHALENE		
BGSN06	0428-07-T28-3	BREECH	5(A) (FT)	0.141	72.899#	1.332	4.018	2.709	1.356	0.413	0.956	5.800		
BGSN07	0428-07-T28-4	BREECH	5(A) (BK)	0.141	0.036	0.009	0.149	0.160	*	0.070	0.034	0.060		
BGSN05	0428-12-T1218-6	BKGD	BACKGROUND	2.154	0.104	0.007	0.292	0.256	0.041	0.146	0.057	0.485		
BGSNQC	0428-14-T28-2	BLANK	BLANK	0	0.038	0.006	0.052	0.116	*	0.034	0.009	0.028		
BGSN48	0809-01-T301	BREECH	2	0.281	4.280	0.928	0.975	0.711	0.152	0.335	0.432	3.524		
BGSN43	0809-02-T302	BREECH	4	0.281	7.861	0.424	1.594	1.735	0.402	0.260	0.877	6.433		
BGSN46	0809-03-T303F	BREECH	6 (FT)	0.281	15.743	0.443	0.741	1.091	0.015	0.107	0.290	1.547		
BGSN44	0809-03-T303B	BREECH	6 (BK)	0.281	0.144	0.028	0.067	0.487	0.044	0.022	0.063	0.124		
BGSN39	0809-05-T304	BREECH	9	0.281	3.892	0.696	0.518	1.140	0.009	0.081	0.167	1.354#		
BGSN41	0809-05-T305	BREECH	11	0.281	6.310	0.605	1.261	1.565	0.337	0.193	0.387	3.918		
BGSN42	0809-08-T306	BKGD	BACKGROUND	0.281	0.125	0.024	0.077	0.313	0.046	0.023	0.050	0.240		
BGSN47	0809-10-T307	BLANK	BLANK	0	0.104	0.019	0.062	0.249	0.055	0.015	0.023	0.051		

= ESTIMATED FROM SATURATED PEAK AREAS.

* = DETECTION LIMIT (0.005 micrograms/SAMPLE)

TABLE 17. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2
- CONCENTRATION OF VOLATILE ORGANIC GASES

SAMPLE NO.	EMISSIONS SOURCE	ROUND NO.	CONCENTRATION OF COLLECTED EMISSIONS (1) (microgram/Liter)									
			BENZENE	ACRYLO-NITRILE	ETHYL BENZENE	TOLUENE	PYRIDINE	STYRENE	CYANO-BENZENE	NAPHTHALENE		
0428-07-T28-3F	BREECH	(2) 5(A) [FT]	518.48	9.41	28.31	18.30	9.45	2.82	6.70		41.06	
0428-07-T28-4B	BREECH	(2) 5(A) [BK]	-0.12	-0.01	0.77	0.17	-0.16	0.38	0.14		0.21	
0428-12-T1218-6	BKGD	BACKGROUND	0.02	-0.00	0.12	0.06	0.01	0.06	0.02		0.21	
0809-01-T301	BREECH	2	15.04	3.27	3.33	2.04	0.44	1.13	1.48		12.43	
0809-02-T302	BREECH	4	27.79	1.47	5.53	5.69	1.33	0.86	3.07		22.78	
0809-03-T303F	BREECH	6 [FT]	55.84	1.54	2.49	3.40	-0.05	0.32	0.98		5.39	
0809-03-T303B	BREECH	6 [BK]	0.33	0.06	0.10	1.25	0.06	0.02	0.17		0.33	
0809-05-T304	BREECH	9	13.66	2.44	1.70	3.57	-0.07	0.22	0.54		4.71	
0809-05-T305	BREECH	11	22.27	2.12	4.34	5.08	1.10	0.62	1.33		13.83	
0809-08-T306	BKGD	BACKGROUND	0.26	0.05	0.13	0.63	0.07	0.02	0.12		0.74	

(1) LESS BLANK CONCENTRATION

(2) [FT] = FRONT COLLECTOR AND [BK] = BACK, OR DOWNSTREAM, COLLECTOR OF A TANDEM PAIR.

TABLE 18. COMBUSTION PRODUCT DATA EXAMPLE: GUN, XM256; BORE, 120 MM; PROPELLANT, JA2
- MOLES OF VOLATILE ORGANICS PER MOLE OF CARBON MONOXIDE

SAMPLE NO.	SOURCE	ROUND NO.	BENZENE	MOLES OF SPECIES PER MOLE OF CARBON MONOXIDE IN SAMPLE (1)						
				ACRYLO- NITRILE	ETHYL BENZENE	TOLUENE	PYRIDINE	STYRENE	CYANO- BENZENE	NAPHTHALENE
0428-07(T28)3F	BREECH	5(A) (FT) (2)	0.0019053	0.0000509	0.0000765	0.0000570	0.0000344	0.0000078	0.0000186	0.0000920
0428-07(T28)4B	BREECH	5(A) (BK) (2)	-0.0000004	-0.0000000	0.0000021	0.0000005	-0.0000007	0.0000010	0.0000004	0.0000005
0428-12(T1218)6	BKGD		BACKGROUND							
0809-01(-T301)	BREECH	2	0.0000315	0.0000101	0.0000051	0.0000036	0.0000009	0.0000018	0.0000024	0.0000158
0809-02(T302)	BREECH	4	0.0000540	0.0000042	0.0000079	0.0000094	0.0000026	0.0000013	0.0000045	0.0000270
0809-03(T303F)	BREECH	6(FT)	0.0001147	0.0000047	0.0000038	0.0000059	-0.0000001	0.0000005	0.0000015	0.0000068
0809-05(T304)	BREECH	9	0.0000288	0.0000076	0.0000026	0.0000064	-0.0000001	0.0000004	0.0000009	0.0000061
0809-05(T305)	BREECH	11	0.0000405	0.0000057	0.0000058	0.0000078	0.0000020	0.0000009	0.0000018	0.0000153
0809-08(T306)	BKGD	BACKGROUND	0.0000044	0.0000013	0.0000017	0.0000091	0.0000012	0.0000002	0.0000016	0.0000078
BREECH 8/09/88 AVG (5)			5.39E-05	6.44E-06	5.05E-06	6.63E-06	1.05E-06	9.45E-07	2.22E-06	1.42E-05
RSD			0.656	0.373	0.399	0.325	1.151	0.614	0.628	0.599

(1) LESS BACKGROUND LEVELS; () = LESS THAN BACKGROUND LEVEL.

(2) (FT) = FRONT COLLECTOR AND (BK) = BACK COLLECTOR OF A TANDOM SET.)

& = SAMPLES USED IN AVERAGING.

organic per mole of carbon monoxide. The latter ratios determined on 04/28/89 based on one test are markedly greater than those determined on 08/09/89.

4.2.7 Results and Computation for the 25 mm, 105 mm, and 155 mm Caliber Guns

Analogous data for the above caliber weapons are presented in Appendix I using identical formatting of the results. Data for the 25 mm and 105 mm caliber weapons include results for breech gases and spent casings with specific samples so identified. For the 25 mm caliber gun, combustion products from spent casings were obtained from a large number of the casings, a total of 70 sampled on 06/06/88 and 32 on 06/23/88. In the 105 mm caliber gun, the spent casing had a volume of ≈ 5 liters and it was not necessary to sample from a collection of multiple casings.

The rounds fired from the 105 mm caliber gun were temperature conditioned at -35°F and $+125^{\circ}\text{F}$. Due to limited availability of rounds and time constraints, both hot and cold rounds had to be sampled. This is indicated in the tabulated data for the weapon. In data obtained for the 155 mm caliber gun (10/06/88) the rounds were all fired at ambient temperature, whereas the rounds sampled on 4/3 and 4/7/89 were all temperature conditioned at 125°F .

With the 155 mm caliber gun, the rounds were known to contain a relatively large amount of potassium sulfate used as a flash suppressant. Accordingly, the aerosol in the breech gases was analyzed for sulfate, Appendix I, Table 39. (The same analysis also yielded value for the nitrate content of the aerosol.)

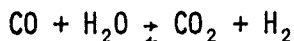
Limited metal particulate analysis on breech gases was made on the 155 mm caliber gun. These data have been tabulated separately at the end of Appendix I, Table 42.

5. DISCUSSION OF RESULTS AND CONCLUSIONS

5.1 THEORETICAL PROPELLANT COMBUSTION PRODUCT DISTRIBUTION VERSUS EXPERIMENTALLY DETERMINED VALUES

Data are presented in Tables 19A through 23A containing selected computed combustion product/CO ratios for several temperatures based on thermodynamic equilibrium calculations for the main propellant charge only together with corresponding experimentally determined values for breech gases determined in this study. The theoretical data in Tables 20 through 22 are based on chemical species listed in the JANNAF Thermochemical Tables,⁽⁵⁾ while data in Table 19 for the WC890 propellant were computed with two species added to those already present in the JANNAF Tables, notably, CH₃CHO and C₆H₆.

Conventional wisdom⁽⁶⁾ suggests that equilibrium between the four species in the reaction:



all of which are major combustion product species in these propellant systems, becomes "frozen in" at temperatures in the 1500-1200K range, i.e., the composition of the breech gases for these four species in the gun barrel samples at ambient temperature should have a composition equivalent to that calculated theoretically for temperatures in the 1500-1200K range. In Tables 19A through 23A the computed ratios, H₂/CO and CO₂/CO at several temperatures in the 1,800-1,000K range are presented and may be compared with the experimentally determined values. Data presented in Table 20A for the M30 propellant indicates that observed and computed ratios at ≈1,400K are in good agreement consistent with the equilibrium involving the four species being "frozen in" at that temperature. In the other propellant systems the agreement between the observed and computed value of the ratios in the 1500-1000K temperature range is clearly not good. For the WC890 propellant (Table 19A) the observed and calculated values of the ratio H₂/CO would agree at some temperature in excess of 1,500K but similar agreement for the CO₂/CO ratio would require a temperature <1,500K. For both JA2 and M30A1 propellants the H₂/CO ratio, computed and

TABLE 19A. SELECTED COMBUSTION PRODUCT RATIOS DETERMINED EXPERIMENTALLY AND THOSE BASED ON THERMODYNAMIC CALCULATIONS AT SEVERAL TEMPERATURES (WC890 MAIN PROPELLANT CHARGE ONLY)

Combustion Product Ratio	Equilibrium Temperature (K) ^a		Observed Ratio ^b (Expt.)
	1500	1000	
H ₂ /CO	0.486	1.05	0.316
CO ₂ /CO	0.257	0.41	0.294
CH ₄ /CO	1.38 x 10 ⁻²	1.01 x 10 ⁻²	2.54 x 10 ⁻³
HCN/CO	9.89 x 10 ⁻⁵	7.31 x 10 ⁻⁶	4.46 x 10 ⁻³
NH ₃ /CO	1.14 x 10 ⁻³	8.20 x 10 ⁻³	1.75 x 10 ⁻²
NO/CO	1.81 x 10 ⁻¹⁰	1.14 x 10 ⁻¹⁴	1.00 x 10 ^{-5c}
SO _x /CO ^d	3.16 x 10 ⁻⁹	1.06 x 10 ⁻⁴	1.75 x 10 ^{-5e}
H ₂ S/CO	2.25 x 10 ⁻³	1.94 x 10 ⁻²	<10 ⁻⁶
CH ₂ O/CO	4.38 x 10 ⁻⁵	1.31 x 10 ⁻⁵	2.06 x 10 ⁻⁷
CH ₃ CHO/CO	2.34 x 10 ⁻⁷	4.06 x 10 ⁻⁷	1.21 x 10 ⁻⁶
C ₆ H ₆ /CO	2.18 x 10 ⁻¹³	2.55 x 10 ⁻¹²	9.45 x 10 ⁻⁶

TABLE 19B. SELECTED COMBUSTION PRODUCT RATIOS DETERMINED EXPERIMENTALLY AND THOSE BASED ON THERMODYNAMIC CALCULATIONS AT SEVERAL TEMPERATURES (WC890 MAIN PROPELLANT CHARGE PLUS ADDITIVES)

Combustion Product Ratio	Equilibrium Temperature (K) ^a		Observed Ratio ^b (Expt.)
	1495	1068	
H ₂ /CO	0.491	0.630	0.316
CO ₂ /CO	0.224	0.508	0.294
CH ₄ /CO	6.59 x 10 ⁻²	6.46 x 10 ⁻²	2.54 x 10 ⁻³
HCN/CO	5.88 x 10 ⁻⁵	6.06 x 10 ⁻⁶	4.46 x 10 ⁻³
NH ₃ /CO	5.90 x 10 ⁻⁴	3.39 x 10 ⁻⁴	1.75 x 10 ⁻²
NO/CO	1.84 x 10 ⁻¹⁰	<10 ⁻¹⁷	1.00 x 10 ^{-5c}
SO _x /CO ^d	1.77 x 10 ⁻⁸	9.2 x 10 ⁻⁴	1.75 x 10 ^{-5e}
H ₂ S/CO	2.09 x 10 ⁻³	2.45 x 10 ⁻³	<10 ⁻⁶
CH ₂ O/CO	2.29 x 10 ⁻⁵	2.53 x 10 ⁻⁶	2.06 x 10 ⁻⁷
CH ₃ CHO/CO	4.10 x 10 ⁻⁸	1.10 x 10 ⁻⁸	1.21 x 10 ⁻⁶
C ₆ H ₆ /CO	-	-	9.45 x 10 ⁻⁶

^aComputation made only for these two temperatures.

^bBreech samples

^cBased on amount of NO₃⁻ formed.

^dSO_x is the sum of SO + SO₂

^eBased on amount of SO₄⁼ formed.

TABLE 20A. SELECTED COMBUSTION PRODUCT RATIOS DETERMINED EXPERIMENTALLY AND THOSE BASED ON THERMODYNAMIC CALCULATIONS AT SEVERAL TEMPERATURES (M30 MAIN PROPELLANT CHARGE ONLY)

Combustion Product Ratio	Equilibrium Temperature (K)					Observed Ratios (a) (Expt.)
	1707	1622	1542	1466	1397	
H ₂ /CO	0.651	0.680	0.713	0.750	0.804	0.808
CO ₂ /CO	0.3956	0.421	0.449	0.481	0.516	0.446
CH ₄ /CO	1.80 x 10 ⁻⁴	2.74 x 10 ⁻⁴	4.38 x 10 ⁻⁴	7.36 x 10 ⁻⁴	1.26 x 10 ⁻³	7.27 x 10 ⁻³
HCN/CO	3.93 x 10 ⁻⁵	3.24 x 10 ⁻⁵	2.69 x 10 ⁻⁵	2.25 x 10 ⁻⁵	1.89 x 10 ⁻⁵	9.04 x 10 ⁻⁵
NH ₃ /CO	7.12 x 10 ⁻⁴	7.13 x 10 ⁻⁴	7.27 x 10 ⁻⁴	7.51 x 10 ⁻⁴	7.83 x 10 ⁻⁴	1.32 x 10 ⁻²
NO/CO	4.12 x 10 ⁻⁸	1.30 x 10 ⁻⁸	3.85 x 10 ⁻⁹	1.07 x 10 ⁻⁹	2.94 x 10 ⁻¹⁰	5.12 x 10 ⁻⁵
SO _x /CO ^b	0 ^c	0	0	0	0	1.02 x 10 ^{-4d}
H ₂ S/CO	0 ^c	0	0	0	0	<10 ⁻⁶
CH ₂ O/CO	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	6.08 x 10 ⁻⁷

TABLE 20B. SELECTED COMBUSTION PRODUCT RATIOS DETERMINED EXPERIMENTALLY AND THOSE BASED ON THERMODYNAMIC CALCULATIONS AT SEVERAL TEMPERATURES (M30 MAIN PROPELLANT CHARGE PLUS ADDITIVES)

Combustion Product Ratio	Equilibrium Temperature (K)					Observed Ratios (a) (Expt.)
	1703	1617	1527	1436	1338	
H ₂ /CO	0.604	0.638	0.678	0.726	0.788	0.808
CO ₂ /CO	0.407	0.430	0.461	0.500	0.553	0.446
CH ₄ /CO	1.17 x 10 ⁻⁴	1.68 x 10 ⁻⁴	2.68 x 10 ⁻⁴	4.96 x 10 ⁻⁴	1.09 x 10 ⁻³	7.27 x 10 ⁻³
HCN/CO	2.99 x 10 ⁻⁵	2.38 x 10 ⁻⁵	1.89 x 10 ⁻⁵	1.49 x 10 ⁻⁵	1.16 x 10 ⁻⁵	9.04 x 10 ⁻⁵
NH ₃ /CO	5.26 x 10 ⁻⁴	5.14 x 10 ⁻⁴	5.12 x 10 ⁻⁴	5.27 x 10 ⁻⁴	5.63 x 10 ⁻⁴	1.32 x 10 ⁻²
NO/CO	3.95 x 10 ⁻⁸	1.23 x 10 ⁻⁸	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	5.12 x 10 ⁻⁵
SO _x /CO ^b	9.21 x 10 ⁻⁶	4.57 x 10 ⁻⁶	1.99 x 10 ⁻⁶	0.733 x 10 ⁻⁶	0.221 x 10 ⁻⁶	1.02 x 10 ⁻⁴
H ₂ S/CO	1.20 x 10 ⁻²	1.35 x 10 ⁻²	1.39 x 10 ⁻²	1.44 x 10 ⁻²	1.50 x 10 ⁻²	<10 ⁻⁶
CH ₂ O/CO	1.25 x 10 ⁻⁵	1.02 x 10 ⁻⁵	0.805 x 10 ⁻⁵	0.632 x 10 ⁻⁵	0.490 x 10 ⁻⁵	6.08 x 10 ⁻⁷

^aBreach Samples

^bNot predicted since pure propellant does not contain any sulfur

^cSO_x is sum of SO + SO₂

^dDetermined as SO₄

TABLE 21A. SELECTED COMBUSTION PRODUCT RATIOS DETERMINED EXPERIMENTALLY AND THOSE BASED ON THERMODYNAMIC CALCULATIONS AT SEVERAL TEMPERATURES (JA2 MAIN PROPELLANT CHARGE ONLY)

Combustion Product Ratio	Equilibrium Temperature (K)					Observed Ratios ^a (Expt.)
	1808	1721	1639	1560	1486	
H ₂ /CO	0.436	0.455	0.472	0.494	0.518	0.556 ^b
CO ₂ /CO	0.340	0.356	0.374	0.394	0.417	0.298
CH ₄ /CO	0.89 x 10 ⁻⁴	1.26 x 10 ⁻⁴	1.87 x 10 ⁻⁴	2.92 x 10 ⁻⁴	4.76 x 10 ⁻⁴	1.31 x 10 ⁻¹
HCN/CO	2.75 x 10 ⁻⁵	2.27 x 10 ⁻⁵	1.89 x 10 ⁻⁵	1.59 x 10 ⁻⁵	1.34 x 10 ⁻⁵	3.74 x 10 ⁻³
NH ₃ /CO	2.58 x 10 ⁻⁴	2.53 x 10 ⁻⁴	2.53 x 10 ⁻⁴	2.55 x 10 ⁻⁴	2.61 x 10 ⁻⁴	5.14 x 10 ⁻²
NO/CO	6.21 x 10 ⁻⁸	2.17 x 10 ⁻⁸	7.13 x 10 ⁻⁹	2.22 x 10 ⁻⁹	6.51 x 10 ⁻¹⁰	4.27 x 10 ⁻⁴
SO _x /CO ^d	0 ^e	0	0	0	0	9.12 x 10 ⁻⁴
H ₂ S/CO	0 ^e	0	0	0	0	2.74 x 10 ⁻⁴
CH ₂ O/CO	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	-
						8.66 x 10 ⁻⁹

TABLE 21B. SELECTED COMBUSTION PRODUCT RATIOS DETERMINED EXPERIMENTALLY AND THOSE BASED ON THERMODYNAMIC CALCULATIONS AT SEVERAL TEMPERATURES (JA2 MAIN PROPELLANT CHARGE PLUS ADDITIVES)

Combustion Product Ratio	Equilibrium Temperature (K)					Observed Ratios ^a (Expt.)
	1785	1688	1600	1510	1414	
H ₂ /CO	0.419	0.440	0.464	0.493	0.528	0.556 ^b
CO ₂ /CO	0.351	0.369	0.389	0.413	0.446	0.298
CH ₄ /CO	0.647 x 10 ⁻⁴	0.966 x 10 ⁻⁴	1.41 x 10 ⁻⁴	2.34 x 10 ⁻⁴	4.59 x 10 ⁻⁴	1.31 x 10 ⁻¹
HCN/CO	2.09 x 10 ⁻⁵	1.69 x 10 ⁻⁵	1.34 x 10 ⁻⁵	1.07 x 10 ⁻⁵	0.845 x 10 ⁻⁵	3.74 x 10 ⁻³
NH ₃ /CO	2.03 x 10 ⁻⁴	2.06 x 10 ⁻⁴	1.94 x 10 ⁻⁴	1.94 x 10 ⁻⁴	2.00 x 10 ⁻⁴	5.14 x 10 ⁻²
NO/CO	4.94 x 10 ⁻⁸	1.46 x 10 ⁻⁸	4.30 x 10 ⁻⁹	1.03 x 10 ⁻⁹	1.86 x 10 ⁻¹⁰	4.27 x 10 ⁻⁴
SO _x /CO	1.00 x 10 ⁻⁵	4.47 x 10 ⁻⁶	2.12 x 10 ⁻⁶	0.873 x 10 ⁻⁶	0.295 x 10 ⁻⁶	9.12 x 10 ⁻⁴
H ₂ S/CO	7.52 x 10 ⁻³	7.30 x 10 ⁻³	7.47 x 10 ⁻³	7.67 x 10 ⁻³	7.91 x 10 ⁻³	2.74 x 10 ⁻⁴
CH ₂ O/CO	1.29 x 10 ⁻⁵	1.03 x 10 ⁻⁵	8.16 x 10 ⁻⁶	3.53 x 10 ⁻⁶	5.00 x 10 ⁻⁶	-
						8.66 x 10 ⁻⁹

^aBreecch Samples

^bData from 8/19/88

^cData from 4/28/88

^dSO_x is sum of SO + SO₂

^eNo^x sulfur in JA2 propellant

^fAnalyses failed - method modified to obtain data on 8/19/88

TABLE 22. SELECTED COMBUSTION PRODUCT RATIOS BASED ON THERMODYNAMIC CALCULATIONS
AT SEVERAL ASSUMED EQUILIBRIUM TEMPERATURES (BENITE PROPELLANT)^(a)

Combustion Product Ratio	Equilibrium Temperature (K)						Observed Ratios (Expt.)
	1710	1648	1589	1531	1475		
H ₂ /CO	0.215	0.226	0.239	0.253	0.269		-
CO ₂ /CO	0.928	0.947	0.968	0.990	1.01		-
CH ₄ /CO	4.45 x 10 ⁻⁶	5.74 x 10 ⁻⁶	7.66 x 10 ⁻⁶	1.06 x 10 ⁻⁵	1.51 x 10 ⁻⁵		-
HCN/CO	4.77 x 10 ⁻⁶	4.06 x 10 ⁻⁶	3.53 x 10 ⁻⁶	3.00 x 10 ⁻⁶	2.60 x 10 ⁻⁶		-
NH ₃ /CO	6.68 x 10 ⁻⁵	6.52 x 10 ⁻⁵	6.44 x 10 ⁻⁵	6.43 x 10 ⁻⁵	6.48 x 10 ⁻⁵		-
NO/CO	7.99 x 10 ⁻⁸	3.52 x 10 ⁻⁸	1.48 x 10 ⁻⁸	6.02 x 10 ⁻⁹	2.34 x 10 ⁻⁹		-
SO/CO	6.21 x 10 ⁻⁵	1.94 x 10 ⁻⁵	5.45 x 10 ⁻⁶	1.40 x 10 ⁻⁶	3.27 x 10 ⁻⁷		-
H ₂ S/CO	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹		-
CH ₂ O/CO	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹		-

(a) Benite was an igniter in the M30, JA2, and M30A1 propellants.

TABLE 23A. SELECTED COMBUSTION PRODUCT RATIOS DETERMINED EXPERIMENTALLY AND THOSE BASED ON THERMODYNAMIC CALCULATIONS AT SEVERAL TEMPERATURES (M30A1 MAIN PROPELLANT CHARGE ONLY)

Combustion Product Ratio	Equilibrium Temperature (K)						Observed Ratios ^a (Expt.)
	1707	1623	1547	1474	1405		
H ₂ /CO	0.645	0.674	0.705	0.740	0.780		0.939
CO ₂ /CO	0.408	0.433	0.462	0.494	0.530		0.211
CH ₄ /CO	1.65 x 10 ⁻⁴	2.50 x 10 ⁻⁴	3.80 x 10 ⁻⁴	6.07 x 10 ⁻⁴	1.03 x 10 ⁻³		5.00 x 10 ⁻²
HCN/CO	3.74 x 10 ⁻⁵	3.09 x 10 ⁻⁵	2.55 x 10 ⁻⁵	2.13 x 10 ⁻⁵	1.79 x 10 ⁻⁵		8.49 x 10 ⁻³
NH ₃ /CO	6.91 x 10 ⁻⁴	6.92 x 10 ⁻⁴	6.97 x 10 ⁻⁴	7.13 x 10 ⁻⁴	7.41 x 10 ⁻⁴		3.66 x 10 ⁻²
NO/CO	4.33 x 10 ⁻⁸	1.38 x 10 ⁻⁸	4.40 x 10 ⁻⁹	1.32 x 10 ⁻⁹	3.69 x 10 ⁻¹⁰		7.37 x 10 ⁻⁵
SO _x /CO ^b	9.68 x 10 ⁻⁵	4.70 x 10 ⁻⁵	1.68 x 10 ⁻⁶	5.24 x 10 ⁻⁷	1.49 x 10 ⁻⁷		3.86 x 10 ⁻²
H ₂ S/CO	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹		2.25 x 10 ⁻²
CH ₂ O/CO	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹	<10 ⁻⁹		6.86 x 10 ⁻⁷

TABLE 23B. SELECTED COMBUSTION PRODUCT RATIOS DETERMINED EXPERIMENTALLY AND THOSE BASED ON THERMODYNAMIC CALCULATIONS AT SEVERAL TEMPERATURES (M30A1 MAIN PROPELLANT CHARGE PLUS ADDITIVES)

Combustion Product Ratio	Equilibrium Temperature (K)						Observed Ratios ^a (Expt.)
	1694	1614	1527	1433	1236		
H ₂ /CO	0.665	0.697	0.735	0.782	0.913		0.939
CO ₂ /CO	0.309	0.306	0.350	0.382	0.486		0.211
CH ₄ /CO	0.86 x 10 ⁻⁴	1.14 x 10 ⁻⁴	1.72 x 10 ⁻⁴	3.10 x 10 ⁻⁴	1.79 x 10 ⁻³		5.00 x 10 ⁻²
HCN/CO	2.54 x 10 ⁻⁵	2.00 x 10 ⁻⁵	1.56 x 10 ⁻⁵	1.20 x 10 ⁻⁵	0.70 x 10 ⁻⁵		8.49 x 10 ⁻³
NH ₃ /CO	3.77 x 10 ⁻⁴	3.59 x 10 ⁻⁴	3.49 x 10 ⁻⁴	3.51 x 10 ⁻⁴	4.01 x 10 ⁻⁴		3.66 x 10 ⁻²
NO/CO	3.06 x 10 ⁻⁸	1.04 x 10 ⁻⁸	2.78 x 10 ⁻⁹	5.47 x 10 ⁻¹⁰	7.72 x 10 ⁻¹²		7.37 x 10 ⁻⁵
SO _x /CO	1.14 x 10 ⁻⁵	6.04 x 10 ⁻⁶	2.72 x 10 ⁻⁶	9.94 x 10 ⁻⁷	1.40 x 10 ⁻⁷		3.86 x 10 ⁻²
H ₂ S/CO	2.12 x 10 ⁻²	2.16 x 10 ⁻²	2.20 x 10 ⁻²	2.25 x 10 ⁻²	2.69 x 10 ⁻²		2.25 x 10 ⁻²
CH ₂ O/CO	9.18 x 10 ⁻⁶	7.23 x 10 ⁻⁶	5.63 x 10 ⁻⁶	4.32 x 10 ⁻⁶	2.46 x 10 ⁻⁶		6.86 x 10 ⁻⁷

^aBreech Samples

^bSO_x is sum of SO + SO₂

observed, could well be in good agreement at some temperature in the 1,500 to 1,000K range. However, the temperature dependence of the CO_2/CO ratio clearly indicates that the observed and computed values of the ratio will never be in agreement within this temperature range.

It should be noted that the thermodynamic equilibrium calculations are made for pure propellant compositions. All the propellant systems studied had additional material present in the reaction zone consisting of primers, Strand Benite and inerts (see Table 1 for details). Thus, the computed combustion product distribution for Strand Benite (Table 22) an ingredient in the JA2 propellant round, has a markedly different combustion product/ CO ratio distribution than that of the main propellant, JA2. With the JA2 propellant system two different sets of experimentally observed combustion product ratios were obtained, one set corresponding to a normal projectile firing (04/28/89) and a second set from firings of a heavier, blunted projectile to maximize gun recoil (08/09/89). Neither set of combustion product ratios is in good agreement with each other or with the theoretical values.

These above computed data are for the main propellant charges only and do not add much support to the suggestion that for the four species, H_2 , CO , CO_2 , and H_2O , equilibrium becomes "frozen in" at temperatures in the range 1500-1200K. However, the conclusion is compromised since the computed values assume a pure propellant whilst in the real world systems studied this was not the case.

In an effort to overcome this deficiency a series of calculations were made for the WC890, JA2, M30, and M30A1 propellants in which the additives to the main charges (Table 1) were included in the combustion product calculations. In order to do this it was necessary to assume that all the materials, main propellant charge plus additives, were homogeneously mixed prior to and after firing the charge. Clearly this assumption is not correct prior to firing the charge. How well mixing of small amounts of additive combustion products with those of the main charge occurs after firing is problematical. Data from these calculations are presented in Tables 19B through 23B. Comparison of the H_2/CO and CO_2/CO computed ratios for the main propellant charge and main propellant charge plus additives show in general only small differences and no improvement in their agreement with the experimental values.

Similarly, the two methods of computations for the minor species/CO combustion product ratios are generally similar, and no consistent improvement in agreement is obtained between the computed and experimentally observed product ratios. Inclusion of the additives in the computations does provide one distinct benefit in those cases where the additives contain sulfur and the main propellant charge does not (e.g., JA2, M30, and M30A1) in so much that sulfur compounds do appear in the computed combustion products in agreement with experimental findings.

Overall, theoretical combustion product calculations for trace species appear to be of little value. Data presented in Tables 19, 20, 21, and 23 show that for the species for which computed and experimental combustion product ratios are available, differences in the latter quantities range from ≈ 2 to 10^6 ignoring the concept of "frozen equilibrium" and trying to obtain the best match between the calculated (any temperature in the range computed) and experimental ratios. In the one propellant where the concept of "frozen equilibrium" appears to apply for H_2 , CO, and CO_2 at $\approx 1,400K$ (i.e., M30) the difference between the computed and experimental ratios ranges from ≈ 6 (CH_4/CO) to 2×10^5 (NO/CO) at the "equilibrium" temperature. This finding implies equilibrium for these species is "frozen in" at temperatures different than those for H_2 , CO and CO_2 . For HCN, NO, and SO_x computed combustion product/CO ratios are most nearly in agreement with observed values at temperatures much greater than 1,500K, in most cases, close to the computed maximum flame temperature of $\approx 2,600K$.

5.2 EXPERIMENTAL DATA FOR INORGANIC GASES/CO AND CH_4/CO COMBUSTION PRODUCT RATIOS

5.2.1 Breech Samples

Experimentally determined average values and relative standard deviations for inorganics gases/CO and CH_4/CO combustion product ratios are presented in Table 24 for the four gun types studied. It is noted that two sets of data are presented for breech gas analyses of the 120 mm and 155 mm caliber weapons. In both cases, the weapons were sampled on different dates and under different conditions. The first set of data for the 120 mm weapon (Table 24) on breech gas samples was made with the gun firing a regular projectile. When obtaining the second set of data, a heavier blunt projectile was fired with

TABLE 24. COMBUSTION PRODUCT DATA EXAMPLE: INORGANIC GASES/CO AND CH₄/CO RATIOS IN COMBUSTION PRODUCTS FROM FOUR GUN TYPES, BREECH, SPENT CASING, AND BORE EVACUATOR SAMPLES

Gun Caliber (mm)	Emissions Source	Moles of Species Per Mole of CO									
		CO ₂	H ₂	CH ₄	HCN	NH ₃	H ₂ S	NO ₂ ⁻	SO ₄ ⁼		
25	Breech	AVG 0.243	2.94E-01 0.243	3.16E-01 0.375	2.54E-03 0.558	4.46E-02 1.370	1.75E-02 0.633	BDL	4.00E-05 2.195	1.75E-05 8.694	
25	Spent Casing	AVG RSD	3.33E-01 0.024	3.49E-01 0.173	BDL ^a	-6.86E-03 ^b 0.656	8.40E-03 0.354	BDL	1.84E-04 1.008	1.56E-04 0.854	
105	Breech	AVG RSD	4.46E-01 0.067	8.08E-01 0.037	7.27E-03 0.260	9.04E-05 0.687	1.32E-02 0.532	BDL	5.12E-05 0.338	1.02E-04 0.504	
105	Spent Casing	AVG RSD	3.74E-01 0.039	6.36E-01 0.195	8.63E-03 0.239	2.21E-02 2.509	1.01E-02 0.094	BDL	9.16E-05 0.739	1.38E-03 0.970	
120	Breech ^c	AVG RSD	4.20E-01 0.051	3.96E-01 0.050	8.70E-02 0.024	2.63E-03 0.133	8.39E-03 0.127	AF ^b	6.30E-05 0.710	6.66E-04 0.686	
120	Breech ^d	AVG RSD	2.98E-01 0.068	5.56E-01 0.043	1.13E-01 0.060	3.74E-03 0.383	5.14E-02 0.112	2.70E-04 0.601	4.27E-04 0.301	9.12E-04 0.580	
155	Breech ^e	AVG RSD	2.11E-01 0.385	9.36E-01 0.064	5.00E-02 0.113	8.49E-03 0.203	3.66E-02 0.588	2.25E-02 0.243	7.37E-05 1.082	3.66E-02 0.292	
155	Breech ^f	AVG RSD	2.99E-01 0.357	7.21E-01 0.131	6.54E-02 0.200	3.23E-03 0.596	6.86E-03 1.068	NA ^g	NA	NA	
155	Breech ^f Evacuator	AVG RSD	3.63E-01 0.526	6.47E-01 0.183	9.45E-02 0.044	-3.14E-04 ^h 0.308	2.85E-03 0.070	NA	NA	NA	
All Calibers	Breech	Low High	2.11E-01 4.46E-01	3.16E-01 9.36E-01	2.54E-03 1.13E-01	9.04E-05 8.49E-03	6.86E-03 5.14E-02	2.70 E-04 2.25E-02	4.00E-05 4.27E-04	1.75E-05 3.66E-02	

^aBelow detection limit.

^bAnalyses failed.

^cSamples collected 04/28/88.

^dSamples collected 08/09/88.

^eSamples collected 10/04/88.

^fSamples collected 03/04/89 and 07/89.

^gNot analyzed.

^hNegative values indicate higher concentration levels of HCN in the background samples than in the combustion product samples.

the object of maximizing the recoil action of the weapon. The first set of data for the 155 mm caliber weapon (10/04/88, Table 24) was obtained on breech gas samples with rounds fired at ambient temperature, whereas when obtaining the second set of data (03/04-07/89) the rounds were conditioned to 125°F. Comparison of these data sets shows that the differing firing conditions for the same propellant had an effect on the combustion product distribution, most marked in 120 mm data, not only for the major species H_2 , CO_2 and CO , but also for the trace species.

The range of values found for the combustion product ratios obtained experimentally for the four weapons and propellant systems studies are summarized at the bottom of Table 24. For the major species H_2 and CO_2 , the high and low values vary by factors of 2.1 and 3, respectively. For the trace species, the low and high values vary by factors ranging from 7.5 (NH_3/CO) to 220 ($SO_4^{=}$). It is noted that differences in computed and experimental combustion product ratios for these same trace species (Section 5.1) varied from a low of 6 to a high of 2×10^5 .

5.2.2 Breech Versus Spent Casing Samples

Experimentally determined average values and relative standard deviations for inorganic gas/ CO and CH_4/CO combustion product ratios are presented in Table 24 for breech and spent casing samples obtained from 25 mm and 105 mm caliber weapons. For both weapons differences between product ratios obtained from breech and spent casing samples are quite small and generally overlap within the stated error limits. For these combustion product species no convincing differences are apparent in data from breech and spent casing samples. As noted earlier, it was not possible to obtain spent casing combustion product samples from the 120 mm (combustible cartridge) and 155 mm (bag charge) weapons.

5.2.3 Breech Versus Bore Evacuator Samples

Experimentally determined average values and relative standard deviations for inorganic gas/ CO and CH_4/CO combustion product ratios are presented in Table 24 for breech and bore evacuator samples obtained from a 155 mm caliber weapon. The data are limited. With the exception of product ratios for CH_4/CO and HCN/CO , the ratios for the other gases are not significantly different from the two sources. Although the breech and bore evacuator ratios

for HCN/CO are markedly different, the negative value for one of the ratios raises significant questions with respect to its validity. The larger value found for the bore evacuator ratio for CH_4/CO compared to the breech value suggests that oxidation of hot gases in the bore evacuator must occur to a very minor degree if at all. It is further noted that the pressure of gas (combustion products plus air originally present) in the evacuator builds up to ≈ 200 psi during its operation. The mole ratio of oxygen to combustible species (H_2 and CO) is about 1:35 at the highest operational pressure, suggesting that at best only a very minor degree of combustion gas oxidation is likely to occur. These findings indicate that oxidation of combustion product gases in the bore evacuator cannot be used to simulate the effect of muzzle flash on the combustion product distribution as was originally hoped.

5.3 EXPERIMENTAL DATA FOR POLYNUCLEAR HYDROCARBONS/CO COMBUSTION PRODUCT RATIOS

Experimentally determined average values and relative standard deviations for PAH/CO combustion product ratios are presented in Table 25. Of the ten PAHs that were assayed, all were detected in the combustion products from all four weapons studies with the exception of anthracene which was absent from the 120 and 155 mm caliber guns. Most of the PAH/CO ratios were in the 10^{-8} - 10^{-10} range with a few values occurring in the 10^{-7} range for the heavier molecular weight PAHs. For the 25 mm and 105 mm caliber weapons, PAH/CO ratios were remarkably similar in both, varying only by a factor of two for the individual ratios. Overall, the PAH/CO ratios were found to be largest in the 155 caliber gun, (anthracene excepted), with all values lying in the 10^{-8} to 10^{-7} range.

5.4 EXPERIMENTAL DATA FOR ALDEHYDE/CO COMBUSTION PRODUCT RATIOS

Experimentally determined average values and relative standard deviations for aldehyde/CO combustion product ratios are presented in Table 26. For the eight aldehydes analyzed, measured aldehyde/CO ratios varied from a high of 3.31×10^{-5} to a low of 1.31×10^{-8} excluding the one zero value. There was a weak indication that aldehyde/CO ratios in the spent casing samples (25 and 105 mm caliber guns) were slightly larger than in the corresponding breech samples.

TABLE 25. PAH/CO RATIOS IN COMBUSTION PRODUCTS FROM FOUR GUN TYPES - BREECH SAMPLES

Gun Caliber (mm)	Emissions Collected	No. of Samples	Moles of PAH Per Mole of CO									
			Phen- anthrene	Anthracene	Fluor- anthene	Pyrene	Benz-a- anthracene	Chrysene	Benz-b- fluoranthene	Benz-k- fluoranthene	Benz-a- pyrene	Benz-ghi- perylene
25	Breech	2 AVG RSD	1.15E-08 0.624	2.76E-10 1.414	2.84E-09 0.458	4.16E-09 0.528	5.16E-10 0.031	7.65E-10 0.500	2.09E-10 0.205	6.34E-10 0.171	4.37E-10 0.941	1.10E-09 1.083
105	Breech	6 AVG RSD	1.51E-08 1.948	6.27E-10 1.674	1.59E-09 0.870	1.90E-09 1.031	3.22E-10 0.506	3.33E-10 0.496	1.11E-10 0.660	5.96E-10 0.751	3.65E-10 0.757	9.31E-10 0.544
120	Breech	5 AVG RSD	1.39E-09 2.548	0.00E+00	6.70E-8 1.104	8.49E-10 0.782	1.23E-09 0.606	1.65E-09 0.695	2.45E-09 0.368	1.25E-08 0.418	2.97E-08 0.378	3.01E-07 0.274
155	Breech	3 AVG RSD	5.68E-08 0.655	0.00E+00	2.38E-08 1.313	4.61E-08 1.451	1.92E-08 1.537	2.32E-08 1.523	1.55E-08 1.484	6.08E-08 1.520	1.07E-07 1.578	5.95E-07 1.540

TABLE 26. ALDEHYDE/CO RATIOS IN COMBUSTION PRODUCTS FROM FOUR GUN TYPES- BREECH AND SPENT CASING SAMPLES

Gun Caliber (mm)	Emissions Collected	No. of Samples	Moles of Aldehyde Per Mole of CO							
			Form- aldehyde	Acet- aldehyde	Acrolein/ Acetone	Propion- aldehyde	Croton- aldehyde	Isobutyl- aldehyde	Benz- Aldehyde	Hexan- aldehyde
25	Breech	5 AVG RSD	2.06E-07 1.541	1.21E-06 0.776	3.61E-06 0.964	3.37E-07	8.75E-08 2.032	1.86E-07 0.749	6.25E-08 0.801	1.17E-07 0.785
25	Spent Casing	4 AVG RSD	7.44E-06 1.306	1.99E-06 0.376	1.91E-05 0.520	BDL	1.88E-08 0.314	4.99E-07 0.356	7.51E-08 0.165	3.39E-07 0.502
105	Breech	4 AVG RSD	6.08E-07 0.856	1.86E-06 0.382	4.82E-06 0.886	1.24E-07 0.753	3.55E-08 0.679	8.69E-07 0.849	5.56E-07 0.449	4.87E-08 0.572
105	Spent Casing	5 AVG RSD	1.32E-05 1.734	4.40E-06 1.543	3.31E-05 1.835	5.32E-07 1.625	6.70E-08 1.223	8.06E-07 1.387	8.36E-07 0.864	4.31E-07 1.205
120	Breech ^a	4 AVG RSD	0	1.44E-07 0.734	1.01E×10 ⁻⁶ 0.265	3.92 E-08 0.784	4.5E-08 0.181	3.66E-08 0.236	2.14E-08 0.664	1.94E-08 0.329
120	Breech ^b	5 AVG RSD	8.66E-08 0.255	1.41E-06 0.327	2.28E-06 0.220	5.56E-08 0.231	0	5.20E-07 0.376	4.49E-07 0.181	3.07E-08 0.434
155	Breech	5 AVG RSD	6.86E-07 1.339	1.86E-07 0.560	1.87E-06 1.200	9.50E-08 0.756	9.45E-08 0.925	4.52E-08 0.412	7.41E-07 1.443	1.31E-08 0.816

^aSamples taken 04/28/88.^bSamples taken 08/09/88.

5.5 EXPERIMENTAL DATA FOR SELECTED VOLATILE ORGANIC/CO COMBUSTION PRODUCT RATIOS

Experimentally determined average values and relative deviations for selected volatile organic/CO combustion product ratios are presented in Table 27. All the Tenax samples collected during the program (≈ 40) were subjected to qualitative GC/MS analyses. However, financial limitations restricted quantification of the data to a relatively small number of collected samples. For the ten organic species analyzed, combustion product ratios varied from a high of 1.64×10^{-4} to a low of 3.28×10^{-7} . There was a weak indication that combustion product ratios for the spent casing samples from the 25 mm caliber gun were slightly larger than those from breech samples. The reverse trend appeared to hold for the 105 mm caliber gun.

5.6 MISCELLANEOUS EXPERIMENTAL DATA ON COMBUSTION PRODUCTS

5.6.1 Sulfate and Nitrate Aerosol in Breech Gases From the M199 Cannon

The charge for the 155 mm caliber cannon contains almost 0.5 kg of potassium sulfate, added as a flash suppressant. When obtaining breech gas samples from the weapon a "dirty white" powder was observed in the Teflon sampling lines. Accordingly, it was deemed worthwhile to determine how much particulate sulfate and nitrate (determined simultaneously during the sulfate analysis) was being collected on the filter preceding the glass flasks in the sampling train. Data are presented in Table 39 in Appendix I. The ratios for NO_3^-/CO in the breech gases and particulate were determined at 7.37×10^{-5} and 4.3×10^{-5} , respectively. The ratios $\text{SO}_4^{2-}/\text{CO}$ were determined at 3.68×10^{-2} (gas phase) and 5.10×10^{-6} (particulate) indicating that most of the sulfur in the breech gases was in the vapor phase whereas for the nitrate it was approximately evenly divided between the two phases. It would thus appear that much of the "dirty white" powder observed in the sampling lines was not potassium sulfate.

5.6.2 Metal Particulate in Breech Gases From the M199 Cannon

The M39A1 charge in the 155 mm caliber cannon contains 0.264 kg of potassium ($\text{K}_2\text{SO}_4 + \text{KNO}_3$), 0.157 kg of metallic lead and 0.499 kg of a material

TABLE 27. SELECTED VOLATILE ORGANICS/CO RATIOS IN COMBUSTION PRODUCTS FROM THREE GUN TYPES - BREECH AND SPENT CASING SAMPLES

Gun Caliber (mm)	Emissions Collected	No. of Samples	Moles of Species Per Mole of CO							
			Benzene	Acrylo- nitrile	Ethyl benzene	Toluene	Pyridine	Styrene	Cyano benzene	Naphtha- lene
25	Breech	2 AVG RSD	9.45E-06 0.260	1.87E-06 0.75	1.45E-06 0.066	2.29E-06 0.455	3.28E-07 0.501	4.88E-07 0.488	6.50E-07 0.222	2.66E-06 0.961
25	Spent Casing	2 AVG RSD	5.21E-05 1.387	1.20E-05 0.852	1.10E-05 0.676	1.37E-05 0.159	9.12E-06 0.324	2.73E-06 1.088	8.86E-06 0.471	1.80E-05 0.639
105	Breech	2 AVG RSD	1.64E-04 0.230	4.17E-05 0.926	1.71E-05 0.397	3.18E-05 0.830	1.48E-05 1.037	2.86E-05 0.925	1.23E-04 1.195	5.11E-05 0.386
105	Spent Casing	2 AVG RSD	2.72E-05 0.917	6.95E-06 1.268	3.21E-06 1.437	3.76E-06 1.083	1.62E-06 0.659	3.75E-06 1.037	9.03E-06 0.079	1.81E-05 0.069
120	Breech	2 AVG RSD	5.39E-05 0.656	6.44E-06 0.373	5.05E-06 0.399	6.63E-06 0.325	1.05E-06 1.151	9.45E-07 0.614	2.22E-06 0.628	1.42E-05 0.599

described as TiO_2/Wax . Analytical data were therefore obtained for the presence of these metals as particulate in the breech gases. These data are presented in Table 44 of Appendix I, and indicate that a much larger fraction of potassium is found in the collected particulate than is found in the starting materials. It is interesting to note that the total particulate concentration analyzed as sulfate and nitrate (Table 38 in Appendix I) at 15 micrograms/liter is much smaller than that of the analyzed particulate potassium, 798 micrograms/liter. Clearly, most of the potassium in the breech particulate is not present as the sulfate or nitrate but is in the form of some other compound.

5.7 OVERVIEW OF EXPERIMENTAL DATA FOR PROPELLANT COMBUSTION PRODUCT/CO RATIOS, BREECH, SPENT CASING, AND BORE EVACUATOR SAMPLES

Experimental data presented in Tables 23 through 26 on the propellant combustion product/CO ratios clearly allow few definitive conclusions to be made with respect to their magnitude and relationship to propellant and gun caliber. The following summarizes the situation.

- (1) For the species studied the compositions of the combustion products found in the breech and spent casing samples appeared to be essentially identical both qualitatively and quantitatively.
- (2) Analyses of residual combustion products sampled from the bore evacuator appeared to have the same qualitative and quantitative composition as those samples from the breech. The effects of muzzle flash on the composition of breech combustion products cannot be determined by sampling gases from the bore evacuator.
- (3) Combustion products were sampled and analyzed from four different caliber weapons each using a different propellant. Under these conditions, it is clearly not possible to relate combustion product/CO ratios to caliber or propellant type dependencies.
- (4) The present data, taken in conjunction with IITRI previous studies, strongly suggest that all propellants containing similar elements will produce qualitatively similar combustion products. The relative amounts of these major and minor species will depend on the propellants' initial stoichiometry, reaction kinetics, and on other factors at present not clearly understood.

- (5) Although the combustion product data generated in the present program are unique to the gun and propellant combination sampled, they can probably be used to provide order of magnitude estimates for the composition of combustion products formed in other weapon and propellant systems.

5.8 OVERVIEW OF CHEMICAL SAMPLING AND ANALYTICAL METHODS USED IN STUDY

5.8.1 Introduction

During the course of the program a number of observations were made indicating that some of the sampling and analytical procedures were not entirely satisfactory. A brief review will be presented.

5.8.2 Inorganic Gases, CO, CO₂, H₂, and CH₄

Analyses of these gases by gas chromatography with thermal conductivity detection appeared to be satisfactory. The presence of basic, acid or organic solvents in the containing glass flasks appeared to have no adverse affects on the data. Combustion samples contained in glass flasks and in metal (steel) cylinders gave analytical results for these species that were not dependent on the containing vessel.

5.8.3 HCN and NH₃ Analyses

Aqueous solutions containing these species were analyzed by TEI Analytical of Niles, Illinois using EPA approved procedures. Data are presented in Tables 3, 4, 19, and 20 of Appendix I, which clearly shows that solutions containing these ions are not stable over a period of several months. In the two examples, the first analyses were made within 19 days (HCN) and 21 days (NH₃) after sample collection. It is not clear to what degree sample deterioration occurred during this interval. On the basis of these results, the sampling and analytical procedures for these two species must be regarded as questionable.

5.8.4 H₂S, SO₄⁼, and NO₃⁻ Analyses

Apart from a minor change in the analytical procedures used with H₂S, previously mentioned, analyses for these species appeared to be satisfactory. However, no temporal studies were made, and it is thus not clear how well the data reflect the true compositions of the breech gases.

5.8.5 PAH Analyses

The PAH sampling and analytical procedures appeared to be adequate for the species quantified. However, in all samples analyzed, >60% of the total sample consisted of unidentified material, presumably PAHs.

5.8.6 Aldehyde Analyses

The aldehyde analyses appear to work satisfactorily in most cases with spiked samples showing acceptable recoveries (80-120% regime). However, there were exceptions as already noted. In particular, the aldehyde samples collected from the breech and bore evacuator (03/89) of the 155 mm caliber gun showed essentially no aldehydes present. Addition of the aldehyde derivatives to the solution and subsequent analyses gave zero recovery, indicating destruction of the derivatives. It is noted that apparently satisfactory aldehyde analyses were generally made on breech combustion product samples collected from a 155 mm caliber gun on 10/88. The temporal stability of the aldehyde samples was not established.

5.8.7 Volatile Organics, Tenax/GCMS Analyses

The sampling and analytical procedures for these species appeared to work satisfactorily based on the limited data quantified. The temporal stability of the procedure was not established.

5.8.8 Conclusions

Clearly, there are difficulties associated with some of the analytical procedures used in this study as noted above and possibly other difficulties not overtly apparent. In general, procedures used in the present program have proved successful in many areas relating to air sampling and analyses. The complexity of the chemical mixtures to be analyzed in gun smoke clearly present problems with respect to the integrity of the analyses. The current program was not charged with the development and validating sampling and analytical procedures for gun smoke analyses but was performed on the assumption that satisfactory methods were available. This study demonstrates that if further useful work is to be performed in the analysis of gun smoke combustion products efforts should be made to assess the reliability of the analytical procedures used. Where doubt exists, the development and validation of suitable sampling and analytical methodology should be initiated.

6. REFERENCES

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APPENDIX I

EXPERIMENTAL COMBUSTION PRODUCT DATA COMPILATIONS
FOR THE 25, 105, AND 155 MM CALIBER GUNS

IIT RESEARCH INSTITUTE

DATA FOR THE 25 MM CALIBER, M242 GUN
WITH WC890 PROPELLANT (BREECH AND
SPENT CASINGS)

IIT RESEARCH INSTITUTE

TABLE 1. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- INORGANIC GASES AND METHANE ANALYSIS RAW DATA

GC RUN NO.	SAMPLE NO.	EMISSIONS SOURCE	GC PEAK AREAS				
			CO2	H2	N2	METHANE	CO
134	0613-001	CALGAS, CT2112	6.15E+06	1.01E+06	5.63E+07	3.67 E+04	1.35E+07
135	0613-002	CALGAS, CT2112	6.35E+06	1.02E+06	5.54E+07	2.37 E+04	1.32E+07
136	060660-01005	RND 60 BREECH, ALD	4.05E+06	6.01E+05	4.17E+07	3.37 E+04	1.33E+07
137	060732-02005	RND 32 BREECH, ALD	9.87E+05	1.01E+05	5.42E+07	7.73 E+03	3.19E+06
138	060733-03005	RND 33 BREECH, ALD	3.54E+06	5.67E+05	4.31E+07	4.17 E+04	1.23E+07
139	060757-04005	RND 57 BREECH, ALD	8.47E+05	4.62E+04	5.47E+07	†	1.98E+06
140	0613-003	CALGAS, CT2112	6.25E+06	9.76E+05	5.63E+07	2.27 E+04	1.29E+07
141	0613-004	CALGAS, CT2112	7.27E+06	1.17E+06	5.37E+07	2.16 E+04	1.30E+07
142	060770-05005	RND 70 BREECH, ALD	8.63E+05	4.97E+04	5.50E+07	†	2.01E+06
143	0606-06005	BACKGROUND, ALD	†	†	5.75E+07	†	†
144	0613-005	CALGAS, CT2112	7.08E+06	1.06E+06	5.30E+07	2.23 E+04	1.28E+07
145	0613-006	CALGAS, CT2112	7.28E+06	1.10E+06	5.50E+07	2.44 E+04	1.31E+07
146	0613-007	CALGAS, CT2112	7.27E+06	1.19E+06	5.45E+07	2.35 E+04	1.31E+07
148	060757-04005	RND 57 BREECH, ALD (GC RERUN)	8.22E+05	4.79E+04	5.48E+07		1.97E+06
149	0614-001	CALGAS, CT2112	7.35E+06	1.07E+06	5.53E+07	2.14 E+04	1.32E+07
150	0606170-08505	RND 1/70 SPENT CASINGS, ALD	7.53E+05	7.22E+04	5.56E+07	†	1.90E+06
151	0606170-07505	RND 1/70 SPENT CASINGS, ALD	1.31E+06	1.06E+05	5.47E+07	†	2.58E+06
152	060620-01001	RND 20 BREECH, HCN	3.55E+06	6.88E+05	4.58E+07	4.89 E+04	1.62E+07
153	060670-02001	RND 70 BREECH, HCN	1.15E+06	1.84E+05	5.91E+07	1.11 E+04	4.68E+06
154	060712-03001	RND 12 BREECH, HCN	2.07E+06	4.12E+05	5.42E+07	2.53 E+04	9.32E+06
155	060738-04001	RND 38 BREECH, HCN	1.53E+06	3.59E+05	5.52E+07	3.18 E+04	8.54E+06
156	060762-05001	RND 62 BREECH, HCN	4.26E+05	1.68E+04	6.26E+07	†	1.48E+06
157	0606-06001	BACKGROUND, HCN	†	†	6.99E+07	†	†
158	0606170-07501	RND 1/70 SPENT CASINGS, HCN	†	1.20E+05	6.11E+07	†	2.90E+06
159	0606170-08501	RND 1/70 SPENT CASINGS, HCN	6.26E+05	8.46E+04	6.16E+07	†	2.10E+06
160	060630-01002	RND 30 BREECH, NH3	4.14E+06	6.65E+05	4.70E+07	2.77 E+04	1.54E+07
161	060703-02002	RND 3 BREECH, NH3	3.66E+06	5.32E+05	5.02E+07	3.70 E+04	1.21E+07
162	0614-002	CALGAS, CT2112	7.26E+06	1.18E+06	5.44E+07	2.44 E+04	1.32E+07
163	060717-03002	RND 17 BREECH, NH3	9.32E+05	5.99E+04	6.13E+07	8.96 E+03	2.53E+06
164	060743-04002	RND 43 BREECH, NH3	1.56E+06	1.58E+05	5.89E+07	5.98 E+03	4.62E+06
165	060764-05002	RND 64 BREECH, NH3	5.92E+05	†	6.29E+07	†	9.98E+05
166	0606-06002	BACKGROUND, NH3	2.44E+05	†	6.36E+07	†	†
167	0606170-07502	RND 1/70 SPENT CASINGS, NH3	1.10E+06	1.12E+05	6.03E+07	†	2.85E+06
168	0606170-08502	RND 1/70 SPENT CASINGS, NH3	8.86E+05	9.14E+04	6.65E+07	†	2.12E+06
169	0614-003	CALGAS, CT2112	7.27E+06	1.18E+06	5.42E+07	2.64 E+04	1.31E+07
170	0614-004	CALGAS, CT2112	7.33E+06	1.09E+06	5.44E+07	2.43 E+04	1.32E+07
171	0615-001	CALGAS, CT2112	7.40E+06	1.09E+06	5.49E+07	2.92 E+04	1.32E+07
172	060640-01003	RND 40 BREECH, H2S	4.03E+06	6.32E+05	4.85E+07	2.55 E+04	1.38E+07
173	060707-02003	RND 7 BREECH, H2S	1.74E+06	2.93E+05	5.68E+07	3.09 E+04	6.60E+06
174	060720-03003	RND 20 BREECH, H2S	1.24E+06	1.52E+05	5.94E+07	1.30 E+04	4.36E+06

TABLE 1. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- INORGANIC GASES AND METHANE ANALYSIS RAW DATA (CONTINUED)

GC RUN NO.	SAMPLE NO.	ELEM SOURCE	GC PEAK AREAS				
			CO2	H2	N2	METHANE	CO
175	060747-04003	RND 47 BREECH, H2S	1.33E+06	1.47E+05	5.94E+07	6.40 E+03	4.30E+06
176	060766-05003	RND 66 BREECH, H2S	2.72E+06	4.46E+05	5.34E+07	1.70 E+04	9.32E+06
177	0615-002	CALGAS, CT2112	7.34E+06	1.20E+06	5.43E+07	2.42 E+04	1.32E+07
178	0606-06003	BACKGROUND, H2S	†	†	6.41E+07	†	†
179	0606170-07503	RND 1/70 SPENT CASING, H2S	9.85E+05	1.15E+05	6.09E+07	†	2.85E+06
180	0606170-08503	RND 1/70 SPENT CASING, H2S	7.59E+05	8.84E+04	6.15E+07	†	2.11E+06
181	060650-01004	RND 50 BREECH, NOx	1.59E+06	3.57E+05	5.33E+07	2.88 E+04	6.90E+06
182	060710-02004	RND 10 BREECH, NOx	1.60E+06	2.99E+05	5.31E+07	2.68 E+04	6.90E+06
183	060723-03004	RND 23 BREECH, NOx	1.47E+06	3.50E+05	5.55E+07	3.17 E+04	6.72E+06
184	0615-003	CALGAS, CT2112	7.17E+06	1.18E+06	5.33E+07	2.33 E+04	1.29E+07
185	060753-04004	RND 53 BREECH, NOx	3.82E+05	†	5.66E+07	†	1.04E+06
186	060766-05004	RND 66 BREECH, NOx	2.45E+05	†	6.10E+07	†	4.44E+05
187	0615-004	CALGAS, CT2112	7.15E+06	1.05E+06	5.33E+07	2.31 E+04	1.26E+07
188	0606-06004	BACKGROUND, NOx	†	†	6.49E+07	†	†
189	0606170-07504	RND 1/70 SPENT CASING, NOx	8.58E+05	1.54E+05	5.76E+07	†	2.71E+06
190	0606170-08504	RND 1/70 SPENT CASING, NOx	6.36E+05	8.06E+04	5.87E+07	†	1.98E+06
191	0615-005	CALGAS, CT2112	7.16E+06	1.10E+06	5.30E+07	2.34 E+04	1.28E+07
192	0616-001	CALGAS, CT2112	7.34E+06	1.12E+06	5.39E+07	2.67E+04	1.30E+07
193	0616-002	CALGAS, CT2112	7.22E+06	1.17E+06	5.33E+07	2.21 E+04	1.29E+07
194	060730-TC306	RND 30 BREECH, TENAX	3.85E+06	7.40E+05	4.63E+07	5.52 E+04	1.61E+07
195	060735-TC307	RND 35 BREECH, TENAX	3.68E+06	6.98E+05	4.75E+07	4.52 E+04	1.62E+07
196	060740-TC308	RND 40 BREECH, TENAX	6.04E+06	1.04E+06	3.83E+07	6.89 E+04	2.71E+07
197	060750-TC309	RND 50 BREECH, TENAX	2.55E+06	3.42E+05	5.50E+07	1.74 E+04	9.96E+06
198	060760-TC310	RND 60 BREECH, TENAX	1.35E+06	1.84E+05	5.77E+07	1.50 E+04	6.74E+06
199	0616-003	CALGAS, CT2112	7.37E+06	1.18E+06	5.46E+07	2.31 E+04	1.32E+07
200	0606170-TC311	RND 1/70 SPENT CASING, TENAX	6.31E+05	4.48E+04	6.42E+07	†	1.23E+06
201	0606170-TC312	RND 1/70 SPENT CASING, TENAX	6.86E+05	6.04E+04	6.38E+07	†	1.54E+06
202	06077180-PC302	RND 71/30 BREECH, PAH	1.06E+06	9.28E+04	6.26E+07	†	2.96E+06
203	0607-BKGD-TC316	BACKGROUND, TENAX	2.84E+05	†	5.51E+07	†	2.14E+05
204	0616-004	CALGAS, CT2112	7.40E+06	1.10E+06	5.46E+07	2.76 E+04	1.32E+07
206	0628-001	CALGAS, CT2112	7.43E+06	1.17E+06	5.46E+07	2.56 E+04	1.32E+07
207	0628-002	CALGAS, CT2112	7.45E+06	1.18E+06	5.48E+07	2.13 E+04	1.32E+07
211	0623132-04505	RND 1-32 SPENT CASING, ALD	4.80E+05	4.29E+04	5.73E+07	†	1.15E+06
212	0623132-05505	RND 1-32 SPENT CASING, ALD	4.27E+05	8.18E+04	5.70E+07	†	8.73E+05
213	0628-003	CALGAS, CT2112	7.46E+06	1.19E+06	5.48E+07	2.64 E+04	1.33E+07
217	0622-06005	BACKGROUND, ALD	†	†	5.76E+07	†	†
218	0623132-04501	RND 1-32 SPENT CASING, HCN	3.72E+05	3.93E+04	6.12E+07	†	1.25E+06
219	0623132-05501	RND 1-32 SPENT CASING, HCN	2.79E+05	3.21E+04	6.33E+07	†	9.81E+05
220	0622-06001	BACKGROUND, HCN	†	†	6.51E+07	†	†
221	0628-004	CALGAS, CT2112	7.38E+06	1.10E+06	5.40E+07	2.83 E+04	1.31E+07
222	0629-001	CALGAS, CT2112	7.49E+06	1.19E+06	5.57E+07	2.18 E+04	1.34E+07
225	0629-002	CALGAS, CT2112	7.47E+06	1.09E+06	5.50E+07	1.85 E+04	1.33E+07

TABLE 1. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- INORGANIC GASES AND METHANE ANALYSIS RAW DATA (CONTINUED)

GC RUN NO.	SAMPLE NO.	EMISSIONS SOURCE	GC PEAK AREAS				
			CO2	H2	N2	METHANE	CO
227	0623132-04502	RND 1-32 SPENT CASING, NH3	5.54E+05	4.39E+04	6.36E+07	†	1.30E+06
228	0623132-05502	RND 1-32 SPENT CASING, NH3	4.53E+05	3.22E+04	6.38E+07	†	1.01E+06
229	0622-06002	BACKGROUND, NH3	†	†	7.17E+07	†	†
230	0629-003	CALGAS, CT2112	7.22E+06	1.09E+06	5.39E+07	2.36E+04	1.30E+07
234	0622-06003	BACKGROUND, H2S	6.41E+05	†	6.53E+07	†	†
235	0623132-04503	RND 1-32 SPENT CASING, H2S	4.47E+05	4.47E+04	6.39E+07	†	1.27E+06
236	0623132-05503	RND 1-32 SPENT CASING, H2S	3.72E+05	3.04E+04	6.40E+07	†	9.88E+05
237	0629-004	CALGAS, CT2112	7.25E+06	1.09E+06	5.42E+07	3.17E+04	1.31E+07
239	0630-001	CALGAS, CT2112	7.29E+06	1.10E+06	5.54E+07	2.38E+04	1.33E+07
243	0622-06004	BACKGROUND, NOx	†	†	6.78E+07	†	†
244	0623132-04504	RND 1-32 SPENT CASING, NOx	3.43E+05	4.11E+04	6.05E+07	†	1.23E+06
245	0623132-05504	RND 1-32 SPENT CASING, NOx	2.75E+05	2.50E+04	6.01E+07	†	9.04E+05
246	0630-002	CALGAS, CT2112	7.17E+06	1.09E+06	5.40E+07	2.88E+04	1.30E+07
247	0630-003	CALGAS, CT2112	7.37E+06	1.08E+06	5.52E+07	2.54E+04	1.33E+07
252	062221-TC305-SC	RND 21 SPENT CASING, TENAX	4.73E+05	4.97E+04	6.49E+07	†	8.27E+05
253	0630-004	CALGAS, CT2112	7.49E+06	1.09E+06	5.55E+07	2.51E+04	1.34E+07
256	0630-005	CALGAS, CT2112	7.40E+06	1.09E+06	5.52E+07	3.54E+04	1.33E+07
257	0701-001	CALGAS, CT2112	7.58E+06	1.10E+06	5.60E+07	2.28E+04	1.36E+07
258	0622-BKGD-TC308	BACKGROUND, TENAX	2.35E+05	†	6.65E+07	†	9.19E+04
259	0623116-PC317	RND 1-16 BREECH, PAH	4.60E+06	5.63E+05	4.97E+07	2.75E+04	1.47E+07
260	06231732-PC318	RND 17-32 BREECH, PAH	3.97E+06	5.33E+05	5.17E+07	2.70E+04	1.30E+07
261	0623132-TC311-SC	RND 1-32 SPENT CASING, TENAX	3.82E+05	2.32E+04	6.61E+07	†	7.78E+05
262	0623132-TC312-SC	RND 1-32 SPENT CASING, TENAX	3.80E+05	2.69E+04	6.56E+07	†	8.64E+05
263	0623-BKGD-TC316	BACKGROUND, TENAX	3.85E+05	2.86E+04	6.61E+07	†	8.64E+05
264	0701-002	CALGAS, CT2112	7.43E+06	1.13E+06	5.56E+07	2.28 E+04	1.34E+07

† = BELOW DETECTION LIMIT (1.00E+02).

TABLE 2. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- INORGANIC GASES AND METHANE CONCENTRATION

GC RUN NO.	SAMPLE NO.	EMISSIONS SOURCE	CONCENTRATION (VOL%)				
			CO2	H2	N2	METHANE	CO
157	0606-06001	BACKGROUND, HCN	†	†	93.02	†	†
166	0606-06002	BACKGROUND, NH3	0.27	†	75.58	†	†
178	0606-06003	BACKGROUND, H2S	†	†	77.41	†	†
188	0606-06004	BACKGROUND, NOx	†	†	78.29	†	†
152	060620-01001	RND 20 BREECH, HCN	3.93	7.32	54.43	0.061	19.38
160	060630-01002	RND 30 BREECH, NH3	4.57	7.08	55.83	0.034	17.49
172	060640-01003	RND 40 BREECH, H2S	4.49	6.78	58.52	0.031	18.00
181	060650-01004	RND 50 BREECH, NOx	1.78	3.83	64.34	0.035	7.97
153	060670-02001	RND 70 BREECH, HCN	1.27	1.96	70.19	0.014	5.32
161	060703-02002	RND 3 BREECH, NH3	4.04	5.66	59.60	0.046	13.80
173	060707-02003	RND 7 BREECH, H2S	1.93	3.14	68.55	0.037	7.63
182	060710-02004	RND 10 BREECH, NOx	1.78	3.21	64.09	0.035	7.97
154	060712-03001	RND 12 BREECH, HCN	2.29	4.38	64.39	0.031	10.61
163	060717-03002	RND 17 BREECH, NH3	1.03	0.64	72.87	0.011	2.38
174	060720-03003	RND 20 BREECH, H2S	1.38	1.64	71.70	0.016	3.04
183	060723-03004	RND 23 BREECH, NOx	1.64	3.76	67.02	0.038	7.77
155	060738-04001	RND 38 BREECH, HCN	1.70	3.82	65.60	0.040	9.72
164	060743-04002	RND 43 BREECH, NH3	1.72	1.69	69.96	0.007	3.26
175	060747-04003	RND 47 BREECH, H2S	1.48	1.57	71.68	0.008	4.97
185	060753-04004	RND 53 BREECH, NOx	0.43	†	68.59	†	1.20
156	060762-05001	RND 62 BREECH, HCN	0.47	0.18	74.40	†	1.68
165	060764-05002	RND 64 BREECH, NH3	0.65	†	74.71	†	1.14
176	060766-05003	RND 66 BREECH, H2S	3.03	4.78	64.40	0.021	10.78
186	060768-05004	RND 68 BREECH, NOx	0.27	†	73.59	†	0.51
158	0606170-07501	RND 1/70 SPENT CASING	0.96	1.27	72.60	†	3.31
167	0606170-07502	RND 1/70 SPENT CASING	1.21	1.19	71.61	†	3.24
179	0606170-07503	RND 1/70 SPENT CASING	1.10	1.24	73.54	†	3.29
189	0606170-07504	RND 1/70 SPENT CASING	0.96	1.65	69.59	†	3.13
159	0606170-08501	RND 1/70 SPENT CASING	0.69	0.90	73.19	†	2.39
168	0606170-08502	RND 1/70 SPENT CASING	0.98	0.97	78.97	†	2.41
180	0606170-08503	RND 1/70 SPENT CASING	0.85	0.95	74.28	†	2.44
190	0606170-08504	RND 1/70 SPENT CASING	0.71	0.87	70.87	†	2.29

TABLE 2. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- INORGANIC GASES AND METHANE CONCENTRATION (CONTINUED)

GC RUN NO.	SAMPLE NO.	EMISSIONS SOURCE	CONCENTRATION (VOL%)				
			CO2	H2	N2	METHANE	CO
218	0623132-04501	RND 1-32 SPENT CASING	0.40	0.39	72.73	†	1.42
227	0623132-04502	RND 1-32 SPENT CASING	0.61	0.47	75.47	†	1.48
235	0623132-04503	RND 1-32 SPENT CASING	0.49	0.47	75.77	†	1.44
244	0623132-04504	RND 1-32 SPENT CASING	0.38	0.44	71.33	†	1.39
219	0623132-05501	RND 1-32 SPENT CASING	0.30	0.33	75.24	†	1.11
228	0623132-05502	RND 1-32 SPENT CASING	0.50	0.33	75.61	†	1.14
236	0623132-05503	RND 1-32 SPENT CASING	0.41	0.33	75.94	†	1.12
245	0623132-05504	RND 1-32 SPENT CASING	0.30	0.27	70.78	†	1.02
220	0622-06001	BACKGROUND, HCN	†	†	77.40	†	†
229	0622-06002	BACKGROUND, NH3	†	†	85.02	†	†
234	0622-06003	BACKGROUND, H2S	0.70	†	77.48	†	†
243	0622-06004	BACKGROUND, NOx	†	†	79.93	†	†

† = BELOW DETECTION LIMIT

TABLE 3. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- HCN ANALYSIS: APPARENT TEMPORAL EFFECTS ON RAW DATA

(1)

TOTAL CYANIDE ANALYSIS
(mg/L)

SAMPLE NO.	SAMPLING DATE	EMISSIONS SOURCE	[A]	[B]	[C]	[C]/[A or B]
			ANALYSIS DATE: 6/27/88]	ANALYSIS DATE: 7/15/88]	REANALYSIS DATE: 8/04/88]	
=====	=====	=====	=====	=====	=====	=====
0606-01001	6/06/88	BREECH	0.96		0.96	1.00
0607-02001	6/07/88	BREECH	5.36		0.59	0.09
0607-03001	6/07/88	BREECH	7.54		0.47	0.06
0607-04001	6/07/88	BREECH	9.09		0.71	0.08
0607-05001	6/07/88	BREECH	7.78		0.30	0.04
0606-06001	6/06/88	BACKGROUND	3.15		0.16	0.05
0606-07501	6/06/88	SPENT CASING	1.55		0.16	0.10
0606-08501	6/06/88	SPENT CASING	1.31		0.22	0.17
0622-06001	6/22/88	BACKGROUND		2.78	0.05	0.02
0623-04501	6/23/88	SPENT CASING		0.76	0.05	0.07
0623-05501	6/23/88	SPENT CASING		0.18	0.14	0.79

(1) SOLUTION VOLUME = 50 ml
DETECTION LIMIT = 0.1 mg/L

TABLE 4. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- NH3 ANALYSIS: APPARENT TEMPORAL EFFECTS ON RAW DATA

(1)

AMMONIA-N ANALYSIS
(mg/L)

SAMPLE NO.	SAMPLING DATE	EMISSIONS SOURCE	[A]	[B]	[C]	[C]/[A or B]
			ANALYSIS DATE: 6/27/88]	ANALYSIS DATE: 7/15/88]	REANALYSIS DATE: 8/04/88]	
=====	=====	=====	=====	=====	=====	=====
0606-01002	6/06/88	BREECH	16.2		79.5	4.9
0607-02002	6/07/88	BREECH	10.8		57.0	5.3
0607-03002	6/07/88	BREECH	9.6		28.5	3.0
0607-04002	6/07/88	BREECH	8.8		32.5	3.7
0607-05002	6/07/88	BREECH	4.0		9.5	2.4
0606-06002	6/06/88	BACKGROUND	0.1		0.3	3.0
0606-07502	6/06/88	SPENT CAS	2.3		6.7	2.9
0606-08502	6/06/88	SPENT CAS	1.8		5.1	2.8
0622-06002	6/22/88	BACKGROUND		0.2	0.2	1.0
0623-04502	6/23/88	SPENT CASING		1.8	1.1	0.6
0623-05502	6/23/88	SPENT CASING		1.8	1.1	0.6

(1) SOLUTION VOLUME = 50 ml
DETECTION LIMIT (0.1 mg/L).

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TABLE 5. GUN M242; BORE, 25 MM; PROPELLANT, WC890
- H₂S ANALYSIS RAW DATA

SAMPLE NO.	EMISSIONS SOURCE	S ²⁻ (from H ₂ S) (micrograms/sample)
0623-04503	SPENT CASING	‡
0623-05503	SPENT CASING	‡
0623-06005	BACKGROUND	‡

‡ = BELOW DETECTION LIMIT (0.4 micrograms)

TABLE 6. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- NO_x AND SO_x ANALYSIS RAW DATA

ANALYSIS NO.	SAMPLE NO.	EMISSIONS SOURCE	(1) TOTAL SAMPLE CONCENTRATION (micrograms/L AIR)	
			NO ₃	SO ₄ ²⁻
0720-07	060650-01004	ROUND 50, BREECH	20.2	41.4
0720-11	060710-02004	ROUND 10, BREECH	22.9	42.8
0720-12	060723-03004	ROUND 23, BREECH	16.2	30.7
0720-13	060753-04004	ROUND 53, BREECH	13.5	9.4
0720-14	060768-05004	ROUND 68, BREECH	8.1	6.7
0720-08	0606-06004	BACKGROUND	9.4	12.0
0720-09	0606170-07504	ROUND 1-70, SPENT CASINGS	13.5	18.7
0720-10	0606170-08504	ROUND 1-70, SPENT CASINGS	10.8	14.7
0720-19	0623-04504	ROUND 1-32, SPENT CASINGS	8.1	16.0
0720-20	0623-05504	ROUND 1-32, SPENT CASINGS	10.8	9.4
0720-21	0622-06004	BACKGROUND	8.1	9.4

(1) DETECTION LIMIT: DL(NO₃) = 0.1 micrograms/L
DL(SO₄) = 0.1 micrograms/L

TABLE 7. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- MASS CONCENTRATION OF INORGANIC GAS EMISSIONS

GC RUN NO.	SAMPLE NO.	EMISSIONS SOURCE	SAMPLE VOLUME (ml)	MASS CONCENTRATION OF GASES (micrograms/Liter)					
				CO	HCN	NH ₃	H ₂ S	NO ₂	SO ₂
157	0606-06001	BACKGROUND, HCN	1024	0	187.0				
166	0606-06002	BACKGROUND, NH ₃	1024	0		5.9			
178	0606-06003	BACKGROUND, H ₂ S	1024	0			††		
188	0606-06004	BACKGROUND, NO _x	1024	0				9.4	2.0
152	060620-01001	RND 20 BREECH, HCN	1024	206,637	57.0				
160	060630-01002	RND 30 BREECH, NH ₃	1024	196,531		961.8			
172	060640-01003	RND 40 BREECH, H ₂ S	1024	179,889			††		
181	060650-01004	RND 50 BREECH, NO _x	1024	89,626				20.2	41.4
153	060670-02001	RND 70 BREECH, HCN	1024	59,823	318.2				
161	060703-02002	RND 3 BREECH, NH ₃	1024	155,096		641.2			
173	060707-02003	RND 7 BREECH, H ₂ S	1024	85,795			††		
182	060710-02004	RND 10 BREECH, NO _x	1024	89,576				22.9	42.6
154	060712-03001	RND 12 BREECH, HCN	1024	119,286	447.7				
163	060717-03002	RND 17 BREECH, NH ₃	1024	32,331		570.0			
174	060720-03003	RND 20 BREECH, H ₂ S	1024	56,610			††		
183	060723-03004	RND 23 BREECH, NO _x	1024	87,282				16.2	30.7
155	060738-04001	RND 38 BREECH, HCN	1024	109,216	539.7				
164	060743-04002	RND 43 BREECH, NH ₃	1024	59,077		522.5			
175	060747-04003	RND 47 BREECH, H ₂ S	1024	55,824			††		
185	060753-04004	RND 53 BREECH, NO _x	1024	13,449				13.5	9.4
156	060762-05001	RND 62 BREECH, HCN	1024	18,924	461.9				
165	060764-05002	RND 64 BREECH, NH ₃	1024	12,767		237.5			
176	060766-05003	RND 66 BREECH, H ₂ S	1024	121,128			††		
186	060768-05004	RND 68 BREECH, NO _x	1024	5,771				8.1	6.7
158	0606170-07501	RND 1/70 SPENT CASINGS, HCN	1024	37,152	92.0				
167	0606170-07502	RND 1/70 SPENT CASINGS, NH ₃	1024	36,402		136.6			
179	0606170-07503	RND 1/70 SPENT CASINGS, H ₂ S	1024	36,960			††		
189	0606170-07504	RND 1/70 SPENT CASINGS, NO _x	1024	35,223				13.5	19.7
159	0606170-08501	RND 1/70 SPENT CASINGS, HCN	1024	26,904	77.8				
168	0606170-08502	RND 1/70 SPENT CASINGS, NH ₃	1024	27,093		106.9			
180	0606170-08503	RND 1/70 SPENT CASINGS, H ₂ S	1024	27,385			††		
190	0606170-08504	RND 1/70 SPENT CASINGS, NO _x	1024	25,739				10.8	14.7

TABLE 7. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- MASS CONCENTRATION OF INORGANIC GAS EMISSIONS (CONTINUED)

GC RUN NO.	SAMPLE NO.	EMISSIONS SOURCE	SAMPLE VOLUME (ml)	MASS CONCENTRATION OF GASES (micrograms/Liter)					
				CO	HCN	NH3	H2S	NO ₂	SO ₂
218	0623132-04501	RND 1-32 SPENT CASING, HCN	1024	15,934	45.1				
227	0623132-04502	RND 1-32 SPENT CASING, NH3	1024	16,589		106.9			
235	0623132-04503	RND 1-32 SPENT CASING, H2S	1024	16,166			‡		
244	0623132-04504	RND 1-32 SPENT CASING, NOx	1024	15,580				8.1	16
219	0623132-05501	RND 1-32 SPENT CASING, HCN	1024	12,518	10.7				
228	0623132-05502	RND 1-32 SPENT CASING, NH3	1024	12,864		106.9			
236	0623132-05503	RND 1-32 SPENT CASING, H2S	1024	12,612			‡		
245	0623132-05504	RND 1-32 SPENT CASING, NOx	1024	11,456				10.9	9.4
220	0622-06001	BACKGROUND, HCN		0	165.1				
229	0622-06002	BACKGROUND, NH3		0		11.9			
234	0622-06003	BACKGROUND, H2S		0			‡		
243	0622-06004	BACKGROUND, NOx		0				8.1	9.4

‡ = BELOW DETECTION LIMIT

‡‡ = COLLECTED, BUT NO QUALITATIVE INDICATION OBSERVED, THEREFORE FURTHER ANALYSIS TERMINATED.

TABLE 8. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- RATIO OF INORGANIC GASES AND METHANE EMISSION
CONCENTRATIONS TO CARBON MONOXIDE CONCENTRATION

SC RUN NO.	SAMPLE NO.	EMISSIONS SOURCE	MOLES OF SPECIES PER MOLE OF CARBON MONOXIDE (1)							
			CO2	H2	METHANE	HCN	NH3	H2S	NO ₂	SO ₂ ⁻
152	060620-01001	RND 20 BREECH, HCN	0.214	0.398	0.0033	-0.0007				
160	060630-01002	RND 30 BREECH, NH3	0.262	0.405	0.0020		0.0080			
172	060640-01003	RND 40 BREECH, H2S	0.281	0.424	0.0019			††		
181	060650-01004	RND 50 BREECH, NOx	0.223	0.480	0.0044				0.000061	0.000074
153	060670-02001	RND 70 BREECH, HCN	0.239	0.369	0.0026	0.0023				
161	060703-02002	RND 3 BREECH, NH3	0.293	0.410	0.0033		0.0067			
173	060707-02003	RND 7 BREECH, H2S	0.253	0.412	0.0049			††		
182	060710-02004	RND 10 BREECH, NOx	0.223	0.402	0.0044				0.000068	0.000100
154	060712-03001	RND 12 BREECH, HCN	0.216	0.413	0.0030	0.0023				
163	060717-03002	RND 17 BREECH, NH3	0.358	0.222	0.0039		0.0287			
174	060720-03003	RND 20 BREECH, H2S	0.274	0.325	0.0031			††		
183	060723-03004	RND 23 BREECH, NOx	0.212	0.484	0.0050				0.000035	0.000062
155	060738-04001	RND 38 BREECH, HCN	0.174	0.393	0.0041	0.0033				
164	060743-04002	RND 43 BREECH, NH3	0.328	0.321	0.0014		0.0144			
175	060747-04003	RND 47 BREECH, H2S	0.298	0.317	0.0016			††		
185	060753-04004	RND 53 BREECH, NOx	0.355	†	†				0.000138	-0.000055
156	060762-05001	RND 62 BREECH, HCN	0.280	0.106	†	0.0151				
165	060764-05002	RND 64 BREECH, NH3	0.576	†	†		0.0298			
176	060766-05003	RND 66 BREECH, H2S	0.281	0.444	0.0019			††		
186	060768-05004	RND 68 BREECH, NOx	0.533	†	†				-0.000102	-0.000268
158	0606170-07501	RND 1/70 SPENT CASING	0.290	0.385	†	-0.0026				
167	0606170-07502	RND 1/70 SPENT CASING	0.374	0.367	†		0.0059			
179	0606170-07503	RND 1/70 SPENT CASING	0.334	0.376	†			††		
189	0606170-07504	RND 1/70 SPENT CASING	0.305	0.527	†				0.000053	0.000055
159	0606170-08501	RND 1/70 SPENT CASING	0.289	0.376	†	-0.0042				
168	0606170-08502	RND 1/70 SPENT CASING	0.406	0.404	†		0.0061			
180	0606170-08503	RND 1/70 SPENT CASING	0.347	0.389	†			††		
190	0606170-08504	RND 1/70 SPENT CASING	0.310	0.378	†				0.000025	0.000031
218	0623132-04501	RND 1-32 SPENT CASING	0.285	0.275	†	-0.0078				
227	0623132-04502	RND 1-32 SPENT CASING	0.411	0.321	†		0.0094			
235	0623132-04503	RND 1-32 SPENT CASING	0.341	0.327	†			†		
244	0623132-04504	RND 1-32 SPENT CASING	0.272	0.317	†				0.000235	0.000299

TABLE 8. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- RATIO OF INORGANIC GASES AND METHANE EMISSION
CONCENTRATIONS TO CARBON MONOXIDE CONCENTRATION (CONTINUED)

GC RUN NO.	SAMPLE NO.	EMISSIONS SOURCE	MOLES OF SPECIES PER MOLE OF CARBON MONOXIDE (1)								
			CO2	H2	METHANE	HCN	NH3	H2S	NO2	SO2	
219	0623132-05501	RND 1-32 SPENT CASING	0.273	0.299	†	-0.0128					
228	0623132-05502	RND 1-32 SPENT CASING	0.434	0.288	†		0.0121				
236	0623132-05503	RND 1-32 SPENT CASING	0.364	0.294	†			†			
245	0623132-05504	RND 1-32 SPENT CASING	0.297	0.265	†				0.000426	0.000239	
BREECH			6/07/88	AVG (5)	2.94E-01	3.16E-01	2.54E-03	4.46E-03	1.75E-02	††	4.00E-05
				RSD	0.243	0.375	0.558	1.370	0.533		2.195
SPENT CASING			6/06/88 AND 6/23/88	AVG (4)	3.33E-01	3.49E-01	†	-6.86E-03	8.40E-03	†	1.84E-04
				RSD	0.024	0.173		-0.656	0.354		1.008

(1) LESS BACKGROUND CONCENTRATIONS

† = BELOW DETECTION LIMIT

†† = COLLECTED, BUT NO QUALITATIVE INDICATION OBSERVED, THEREFORE FURTHER ANALYSIS TERMINATED.

TABLE 9. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- PAH ANALYSIS RAW DATA

MASS CONCENTRATION OF PAH IN COLLECTED SAMPLES (micrograms/Liter)											
ANALYSIS NO.	EMISSIONS SOURCE	SAMPLE VOLUME (LITERS)	PHEN-ANTHRENE	FLUOR-ANTHRENE	PYRENE	BENZ-a-ANTHRACENE	CHRYSENE	F LUDRANTHRENE	BENZ-k-FLUORANTHRENE	BENZ-a-PYRENE	BENZ-ghi-PERLENE
3-301	BACKGROUNDP, PAH	10.0	7.90E-04	7.82E-04	9.93E-04	6.70E-05	1.86E-04	9.00E-05	2.70E-04	2.21E-04	7.06E-04
3-302	BREECH PAH, RND 71-80	10.0	1.52E-03	1.01E-03	7.01E-04	1.60E-04	1.50E-04	6.00E-05	1.87E-04	4.90E-05	9.50E-05
4-306F	BREECH PAH, RND 1-16, FILTER ONLY	16.0	1.97E-03	6.25E-05	2.02E-03	7.25E-03	6.17E-04	1.48E-03	1.14E-03	1.21E-03	3.56E-03
4-306P	BREECH PAH, RND 1-16, PUF ONLY	16.0	1.75E-02	5.88E-04	5.39E-04	3.87E-04	1.44E-04	8.06E-05	4.19E-05	†	†
4-307F	BREECH PAH, RND16-32, FILTER ONLY	16.0	2.49E-03	1.56E-04	1.77E-03	4.08E-03	4.34E-04	5.17E-04	6.25E-04	6.56E-04	1.75E-02

† = BELOW DETECTION LIMIT; DETECTION LIMITS - RESPECTIVELY, 1E-04 TO 5E-03 micrograms/L; SEE TEXT.

TABLE 10. GUN, M242; BORE, 25 MM; PROPELLANT WC890 - RATIO OF PAH
CONCENTRATIONS TO CARBON MONOXIDE CONCENTRATION

MOLES OF PAH SPECIES PER MOLE OF CARBON MONOXIDE										
ANALYSIS NO.	EMISSIONS SOURCE	PHEN-ANTHRENE	FLUOR-ANTHRENE	PYRENE	BENZ-a-ANTHRACENE	CHRYSENE	BENZ-b-FLUORANTHRENE	BENZ-k-FLUORANTHRENE	BENZ-a-PYRENE	BENZ-ghi-PERLENE
0607-37	BREECH PAH, RND 71-80	6.42E-09	3.76E-09	2.61E-09	5.27E-10	4.94E-10	1.79E-10	5.58E-10	1.46E-10	2.59E-10
0623-01	BREECH PAH, RND 1-16, FILTER ONLY	1.67E-09	1.52E-09	5.43E-09	4.09E-10	9.82E-10	2.23E-10	6.86E-10	7.28E-10	1.95E-09
0623-01	BREECH PAH, RND 1-16, PUF ONLY	1.49E-08	4.99E-10	2.90E-10	9.53E-11	5.35E-11	1.65E-11	2.51E-11	†	†
0623-02	BREECH PAH, RND16-32, FILTER ONLY	2.36E-09	1.49E-10	3.42E-09	3.22E-10	3.84E-10	1.45E-10	4.20E-10	4.41E-10	1.07E-08
BREECH PAH, AVG (2)		1.15E-08	2.76E-10	2.84E-09	5.16E-10	7.55E-10	2.09E-10	6.34E-10	4.37E-10	1.10E-09
RSD		0.624	1.414	0.453	0.031	0.506	0.205	0.171	0.941	1.083

† = BEYOND DETECTION LIMIT

† = BELOW DETECTION LIMIT

TABLE 11. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- ALDEHYDE ANALYSIS RAW DATA

ANALYSIS NO.	SAMPLE NO.	EMISSIONS SOURCE	ROUND	MASS CONCENTRATION OF ALDEHYDES (1) (micrograms/Liter)							
				FORM- ALDEHYDE	ACET- ALDEHYDE	ACROLEIN/ ACETONE	PROPION- ALDEHYDE	CROTON- ALDEHYDE	ISOBUTYL- ALDEHYDE	BENZ- ALDEHYDE	HEXAN- ALDEHYDE
3-1	0606-60-01-005	BREECH	60	0.01	1.41	1.56	0.58	0.01	0.20	0.26	0.31
3-2	0607-32-02-005	BREECH	32	0.34	0.70	7.79	0.18	0.01	0.29	0.04	0.15
3-3	0607-33-03-005	BREECH	33	0.31	1.35	2.61	0.36	0.01	0.38	0.15	0.18
3-4	0607-57-04-005	BREECH	57	0.01	0.97	2.18	0.15	0.22	0.22	0.12	0.21
3-5	0607-70-05-005	BREECH	70	0.01	0.40	1.46	0.22	0.01	0.08	0.07	0.12
3-6	0606-06-005	BKGD	BKGD	6.17	0.88	0.68	0.20	0.01	0.10	0.10	0.07
3-7	0606-1/70-07-505	SPENT CASING	(1-70)[A]	0.25	1.40	4.98	0.25	0.01	0.41	0.12	0.21
3-8	0606-1/70-08-505	SPENT CASING	(1-70)[B]	1.75	0.36	7.53	0.18	0.01	0.23	0.06	0.51
4-4	0623-1/32-04-505	SPENT CASING	(1-32)[A]	4.25	0.58	9.96	0.09	0.01	0.37	0.05	0.21
4-5	0623-1/32-05-505	SPENT CASING	(1-32)[B]	0.17	0.59	9.29	0.08	0.01	0.17	0.04	0.15
4-6	0622-06-005	BKGD	BKGD	9.47	0.24	40.72	0.02	0.01	0.04	0.05	0.03

(1) COLLECTED SAMPLE VOLUME = 1024 ML/EACH
DETECTION LIMIT = 0.01 micrograms/L

TABLE 12. GUN, M242; BORE, 25 MM; PROPELLANT, WC890 - RATIO OF ALDEHYDE CONCENTRATION TO CARBON MONOXIDE CONCENTRATION

		MOLES OF ALDEHYDE PER MOLE OF CARBON MONOXIDE (1)									
ANALYSIS NO	SAMPLE NO.	SOURCE	ROUND	FORM-ALDEHYDE	ACET-ALDEHYDE	ACROLEIN/ACETONE	PROPION-ALDEHYDE	CROTON-ALDEHYDE	ISOBUTYL-ALDEHYDE	BENZ-ALDEHYDE	HEXAN-ALDEHYDE
3-1	0605-60-01-005	BREECH	60	5.38E-09	5.13E-07	4.33E-07	†	2.46E-09	4.45E-08	3.91E-08	4.95E-08
3-2	0607-32-02-005	BREECH	32	7.61E-07	1.06E-06	8.98E-06	†	9.55E-09	2.70E-07	2.59E-08	9.72E-08
3-3	0607-33-03-005	BREECH	33	1.80E-07	5.30E-07	7.78E-07	†	2.47E-09	8.93E-08	2.50E-08	3.19E-08
3-4	0607-57-04-005	BREECH	57	4.23E-08	2.80E-06	4.76E-06	3.31E-07	4.05E-07	3.85E-07	1.43E-07	2.61E-07
3-5	0607-70-05-005	BREECH	70	4.14E-08	1.13E-06	3.11E-06	†	1.77E-08	1.43E-07	8.00E-08	1.45E-07
M25		BREECH	ALDEHYDE, AVG (4)	2.08E-07	1.21E-06	3.61E-06	6.62E-08	8.75E-08	1.86E-07	6.25E-08	1.17E-07
		RSD		1.541	0.775	0.954		2.032	0.749	0.801	0.785
3-7	0606-170-07-505	SPENT CASING	(1-70)[A]	6.83E-07	2.63E-06	7.13E-06	†	1.19E-08	4.65E-07	9.33E-08	1.76E-07
3-8	0606-170-08-505	SPENT CASING	(1-70)[B]	6.64E-06	9.39E-07	1.48E-05	†	1.63E-08	3.58E-07	6.62E-08	5.77E-07
4-4	0623-132-04-505	SPENT CASING	(1-32)[A]	2.14E-05	2.00E-06	2.60E-05	†	2.16E-08	7.57E-07	7.25E-08	3.21E-07
4-5	0623-132-05-505	SPENT CASING	(1-32)[B]	1.01E-06	2.39E-06	2.83E-05	†	2.53E-08	4.16E-07	6.84E-08	2.81E-07
M25		SPENT CASING	ALDEHYDE, AVG (4)	7.44E-06	1.99E-06	1.91E-05	†	1.86E-08	4.99E-07	7.51E-08	3.39E-07
		RSD		1.306	0.376	0.520	0.000	0.314	0.356	0.165	0.502

(1) BACKGROUND NOT SUBTRACTED FROM ALDEHYDE LEVELS.

† = BELOW ANALYSIS LIMITS

TABLE 13. GUN, M242; BORE, 25 MM; PROPELLANT, WC890
- VOLATILE ORGANIC GASES, GC/MS RAW DATA

COLLECTED VOLATILE ORGANIC GASES (micrograms)												
GC/MS ANALYSIS NO	SAMPLE NO.	EMISSIONS SOURCE	ROUND NO.	SAMPLE VOLUME (LITER)	BENZENE	ACRYLO- NITRILE	ETHYL BENZENE	TOLUENE	PYRIDINE	STYRENE	CYANO- BENZENE	NAPHTHALENE
=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
BGSN15	0520-23-T315	BLANK	BLANK	0.000	0.014	0.006	0.008	0.046	0.024	†	0.013	†
BGSN23	0606-09-T311	SPENT CASING	1/70(C)	0.281	1.309	0.206	0.376	0.718	0.061	0.160	0.177	0.123
BGSN25	0607-24-T303	BREECH	40	0.281	2.777	0.722	0.500	0.720	0.160	0.209	0.596	0.073
BGSN27	0607-22-T302	BREECH	35 [FT]	0.281	3.089	0.374	0.550	0.634	0.148	0.133	0.211	0.411
BGSN22	0607-22-T314	BREECH	35 [BK]	0.281	0.065	0.050	0.136	0.313	0.165	0.028	0.110	0.229
BGSN29	0606-10-T312	SPENT CASING	1/70(D)	0.281	1.637	0.211	0.379	0.414	0.136	0.116	0.255	0.689
BGSN40	0622-07-T308	SPENT CASING	23 [BK]	0.281	0.042	0.013	0.022	0.151	0.005	0.006	0.051	0.052
					†	†	†	†	†	†	†	†
BGSN38	0623-07-T316	BKGD	BKGD	0.281	0.713	0.088	0.141	2.002	0.033	0.041	0.100	0.226
BGSN47	0809-10-T307	BLANK	BLANK	0.000	0.104	0.019	0.062	0.249	0.055	0.015	0.023	0.051
† DETECTION LIMIT (0.005 micrograms/SAMPLE)												

† DETECTION LIMIT (0.005 micrograms/SAMPLE)

TABLE 14. GUN, M242; BORE, 25 MM; PROPELLANT, WC890 - RATIO OF VOLATILE ORGANIC GASES CONCENTRATIONS TO CARBON MONOXIDE CONCENTRATION

SAMPLE NO.	EMISSIONS SOURCE	(1) ROUND NO.	MOLES OF SPECIES PER MOLE OF CARBON MONOXIDE (1)							
			BENZENE	ACRYLO-NITRILE	ETHYL BENZENE	TOLUENE	PYRIDINE	STYRENE	CYANO-BENZENE	NAPHTHALENE
0607-22-T302F	BREECH	35 [FT] (2)	7.72E-06	1.77E-06	1.52E-06	3.03E-06	2.12E-07	6.56E-07	7.52E-07	4.47E-06
0607-22-T314B	BREECH	35 [BK] (2)	1.67E-05	6.44E-06	2.08E-06	3.04E-06	8.12E-07	8.81E-07	2.71E-06	2.53E-06
0607-24-T303	BREECH	40	1.12E-05	1.97E-06	1.38E-06	1.55E-06	4.44E-07	3.20E-07	5.48E-07	8.52E-07
0606-09-T311	SPENT CASING	1/70(C)	1.02E-06	4.77E-06	5.74E-06	1.22E-05	1.12E-05	6.29E-07	5.91E-06	9.84E-06
0606-10-T312	SPENT CASING	1/70(D)	1.03E-04	1.92E-05	1.62E-05	1.53E-05	7.04E-06	4.83E-06	1.18E-05	2.61E-05
BREECH		AVG (2)	9.45E-06	1.87E-06	1.45E-06	2.29E-06	3.28E-07	4.88E-07	6.50E-07	2.66E-06
		RSD	0.260	0.077	0.066	0.455	0.501	0.488	0.222	0.961
SPENT CASING		AVG (2)	5.21E-05	1.20E-05	1.10E-05	1.37E-05	9.12E-06	2.73E-06	8.86E-06	1.80E-05
		RSD	1.387	0.852	0.676	0.159	0.324	1.088	0.471	0.639

(1) LESS BACKGROUND LEVELS.

(2) [FT] = FRONT COLLECTOR; AND [BK] = BACK COLLECTOR OF A TANDUM SET.

DATA FOR THE 105 MM CALIBER M68 GUN WITH M30
PROPELLANT (BREECH AND SPENT CASINGS)

TABLE 15 GUN, M68; BORE, 105 MM; PROPELLANT, M30 - INORGANIC
GASES AND METHANE ANALYSIS RAW DATA

GC RUN NO.	ANALYSIS NO.	EMISSIONS SOURCE	GC PEAK AREAS				
			CO2	H2	N2	METHANE	CO
68	0520-001	CALGAS, CT2112	5.97E+03	9.84E+05	5.58E+07	3.32E+04	1.30E+07
69	052010A-01-001	RND 10(A) COLD,BREECH, HCN	7.10E+06	1.26E+06	4.31E+07	8.80E+04	1.53E+07
70	052010A-01-005	RND 10(A) COLD,BREECH, ALD	6.41E+06	1.14E+06	3.93E+07	8.07E+04	1.38E+07
71	052007-05-400	RND 7 PAH	2.55E+06	4.69E+05	5.71E+07	3.67E+04	5.37E+06
72	052002-02-400	RND 2 PAH	2.79E+06	4.56E+05	5.04E+07	3.40E+04	5.35E+06
73	052005-04-400	RND 5 PAH	2.99E+06	5.40E+05	5.56E+07	4.17E+04	5.24E+06
74	0523-002	CALGAS, CT2112	6.46E+06	1.05E+06	5.44E+07	3.03E+04	1.29E+07
75	052010A-01-003	RND 10(A) COLD,BREECH, H2S	5.30E+06	8.97E+05	4.78E+07	6.75E+04	1.13E+07
76	052010B-02-003	RND 10(B) COLD,BREECH, H2S	6.31E+06	1.11E+06	4.43E+07	7.18E+04	1.36E+07
77	052010C-03-003	RND 10(C) COLD,BREECH, H2S	3.51E+06	6.73E+05	5.31E+07	5.09E+04	7.85E+06
78	052013-04-003	RND 13 HOT,BREECH, H2S	4.69E+06	1.01E+06	4.76E+07	1.16E+05	1.13E+07
79	052015-05-003	RND 15 HOT,BREECH, H2S	1.88E+06	3.45E+05	5.73E+07	3.05E+04	4.19E+06
80	0520-06-003	BACKGROUND, H2S	†	†	6.30E+07	†	†
81	0523-003	CALGAS, CT2112	6.47E+06	1.02E+06	5.36E+07	2.10E+04	1.28E+07
82	0524-001	CALGAS, CT2112	7.26E+06	1.05E+06	5.44E+07	2.82E+04	1.29E+07
83	052011-07-503	RND 11 HOT,SPENT CASING, H2S	6.26E+06	1.27E+06	4.52E+07	1.19E+05	1.52E+07
84	052012-08-503	RND 12 HOT,SPENT CASING, H2S	5.80E+06	1.02E+06	4.54E+07	1.28E+05	1.44E+07
85	0524-002	CALGAS, CT2112	7.22E+06	1.08E+06	5.34E+07	2.52E+04	1.30E+07
86	052010B-02-005	RND 10(B) COLD,BREECH, ALD	5.74E+06	1.04E+06	3.79E+07	7.14E+04	1.27E+07
87	052010C-03-005	RND 10(C) COLD,BREECH, ALD	2.39E+05	†	5.79E+07	†	†
88	052013-04-005	RND 13 HOT,BREECH, ALD	4.23E+06	8.93E+05	4.36E+07	1.03E+05	1.06E+07
89	052015-05-005	RND 15 HOT,BREECH, ALD	1.76E+06	3.32E+05	5.26E+07	2.41E+04	3.81E+06
90	0520-06-005	BACKGROUND, ALD	2.93E+05	†	5.76E+07	†	†
91	052011-07-505	RND 11 HOT,SPENT CASING, ALD	5.16E+06	9.97E+05	4.03E+07	1.04E+05	1.32E+07
92	052012-08-505	RND 12 HOT,SPENT CASING, ALD	5.00E+06	9.57E+05	4.20E+07	1.23E+05	1.31E+07
93	0524-003	CALGAS, CT2112	7.23E+06	1.18E+06	5.40E+07	2.07E+04	1.32E+07
94	052010A-TC306	RND 10(A) COLD,BREECH, TENAX	4.62E+06	8.10E+05	5.15E+07	5.52E+04	1.03E+07
95	0524-004	CALGAS, CT2112	7.32E+06	1.06E+06	5.45E+07	2.10E+04	1.32E+07
96	052010B-TC307	RND 10(B) COLD,BREECH, TENAX	4.93E+06	9.46E+05	4.99E+07	6.34E+04	1.13E+07
97	052013-TC308	RND 13 HOT,BREECH, TENAX	4.02E+06	9.05E+05	5.16E+07	8.43E+04	9.99E+06
98	052015-TC309	RND 15 HOT,BREECH, TENAX	2.11E+06	4.03E+05	5.87E+07	3.40E+04	4.82E+06
100	052013-TC311	RND 13 HOT,SPENT CASING, TENAX	3.54E+06	6.66E+05	5.33E+07	1.20E+05	1.00E+07
101	052014-TC312	RND 14 HOT,SPENT CASING, TENAX	3.55E+06	6.04E+05	5.39E+07	9.08E+04	1.01E+07
102	0524-005	CALGAS, CT2112	7.23E+06	1.07E+06	5.41E+07	2.89E+04	1.31E+07
103	0525-001	CALGAS, CT2112	7.42E+06	1.09E+06	5.59E+07	2.42E+04	1.34E+07
104	0525-002	CALGAS, CT2112	7.48E+06	1.11E+06	5.55E+07	2.39E+04	1.35E+07
105	052010B-02-001	RND 10(B) COLD,BREECH, HCN	5.86E+06	1.02E+06	4.76E+07	7.33E+04	1.31E+07
106	052010C-03-001	RND 10(C) COLD,BREECH, HCN	4.60E+06	8.53E+05	5.08E+07	6.39E+04	1.07E+07
107	052013-04-001	RND 13 HOT,BREECH, HCN	4.62E+06	1.02E+06	4.90E+07	1.12E+05	1.17E+07
108	052015-05-001	RND 15 HOT,BREECH, HCN	1.68E+06	3.52E+05	5.89E+07	3.50E+04	4.34E+06

TABLE 15. GUN, M68; BORE, 105 MM; PROPELLANT, M30 - INORGANIC
GASES AND METHANE ANALYSIS RAW DATA (CONTINUED)

GC RUN NO.	ANALYSIS NO.	EMISSIONS SOURCE	GC PEAK AREAS				
			CO2	H2	N2	METHANE	CO
109	0520-06-001	BACKGROUND, HCN	†	†	6.50E+07	†	†
110	052011-07-501	RND 11 HOT, SPENT CASING, HCN	5.60E+06	1.11E+06	4.57E+07	1.10 E+05	1.43E+07
111	052012-08-501	RND 12 HOT, SPENT CASING, HCN	5.55E+06	9.65E+05	4.79E+07	1.31 E+05	1.44E+07
112	0525-003	CALGAS, CT2112	7.23E+06	1.08E+06	5.41E+07	2.29 E+04	1.31E+07
113	052010A-01-002	RND 10(A) COLD, BREECH, NH3	6.89E+06	1.08E+06	4.62E+07	3.08 E+04	1.42E+07
114	052010B-02-002	RND 10(B) COLD, BREECH, NH3	6.91E+06	1.09E+06	4.45E+07	9.22 E+04	1.44E+07
115	052010C-03-002	RND 10(C) COLD, BREECH, NH3	4.68E+06	8.65E+05	5.07E+07	6.16 E+04	1.02E+07
116	052013-04-002	RND 13 HOT, BREECH, NH3	5.14E+06	9.82E+05	4.85E+07	1.15 E+05	1.19E+07
117	052015-05-002	RND 15 HOT, BREECH, NH3	1.99E+06	3.67E+05	5.91E+07	2.34 E+04	4.31E+06
118	0520-06-002	BACKGROUND, NH3	†	†	6.46E+07	†	†
119	052011-07-502	RND 11 HOT, SPENT CASING, NH3	6.27E+06	1.16E+06	4.51E+07	1.23 E+05	1.50E+07
120	052012-08-502	RND 12 HOT, SPENT CASING, NH3	5.90E+06	9.80E+05	4.67E+07	1.31 E+05	1.45E+07
121	0525-004	CALGAS, CT2112	7.21E+06	1.08E+06	5.39E+07	2.98 E+04	1.31E+07
122	052010A-01-004	RND 10(A) COLD, BREECH, NOx	6.91E+06	1.12E+06	4.30E+07	8.49E+04	1.52E+07
123	052010B-02-004	RND 10(B) COLD, BREECH, NOx	6.50E+06	1.11E+06	4.49E+07	8.43E+04	1.44E+07
124	052010C-03-004	RND 10(C) COLD, BREECH, NOx	4.38E+06	8.71E+05	5.04E+07	5.18E+04	1.04E+07
125	052013-04-004	RND 13 HOT, BREECH, NOx	4.63E+06	9.50E+05	4.77E+07	1.13E+05	1.17E+07
126	052015-05-004	RND 15 HOT, BREECH, NOx	1.67E+06	3.50E+05	5.83E+07	2.61E+04	4.24E+06
127	0520-06-004	BACKGROUND, NOx	†	†	6.77E+07	†	†
128	052011-07-504	RND 11 HOT, SPENT CASING, NOx	5.49E+06	1.17E+06	4.26E+07	1.10E+05	1.39E+07
129	052012-08-504	RND 12 HOT, SPENT CASING, NOx	5.29E+06	9.59E+05	4.43E+07	2.24E+05	1.35E+07
130	0525-005	CALGAS, CT2112	7.18E+06	1.06E+06	5.39E+07	2.07E+04	1.30E+07
206	0628-001	CALGAS, CT2112	7.43E+06	1.17E+06	5.46E+07	2.56E+04	1.32E+07
207	0628-002	CALGAS, CT2112	7.45E+06	1.18E+06	5.48E+07	2.13E+04	1.32E+07
208	062221-01505	RND 21 SPENT CASING, ALD	6.35E+05	8.05E+04	5.70E+07	2.27E+04	1.32E+06
209	062222-02505	RND 22 SPENT CASING, ALD	6.66E+05	9.18E+04	5.66E+07	2.32E+04	1.44E+06
210	062223-03505	RND 23 SPENT CASING, ALD	5.91E+05	5.14E+04	5.69E+07	9.00E+03	1.24E+06
213	0628-003	CALGAS, CT2112	7.46E+06	1.19E+06	5.48E+07	2.64E+04	1.33E+07
214	062221-01501	RND 21 SPENT CASING, HCN	4.73E+05	8.27E+04	6.31E+07	1.44E+04	1.48E+06
215	062222-02501	RND 22 SPENT CASING, HCN	5.20E+05	1.43E+05	6.25E+07	1.67E+04	1.63E+06
216	062223-03501	RND 23 SPENT CASING, HCN	4.19E+05	7.15E+04	6.32E+07	†	1.43E+06
217	0622-06005	BACKGROUND, ALD	†	†	5.76E+07	†	†
220	0622-06001	BACKGROUND, HCN	†	†	6.51E+07	†	†
221	0628-004	CALGAS, CT2112	7.38E+06	1.10E+06	5.40E+07	2.83E+04	1.31E+07
222	0629-001	CALGAS, CT2112	7.49E+06	1.19E+06	5.57E+07	2.18E+04	1.34E+07
223	062221-01502	RND 21 SPENT CASING, NH3	6.76E+05	7.97E+04	6.28E+07	9.89E+03	1.06E+06
224	062222-02502	RND 22 SPENT CASING, NH3	7.28E+05	1.14E+05	6.28E+07	1.29E+04	1.61E+06
225	0629-002	CALGAS, CT2112	7.47E+06	1.09E+06	5.50E+07	1.89E+04	1.33E+07
226	062223-03502	RND 23 SPENT CASING, NH3	6.38E+05	7.24E+04	6.32E+07	1.13E+04	1.38E+06

TABLE 15. GUN, M68; BORE, 105 MM; PROPELLANT, M30 - INORGANIC
GASES AND METHANE ANALYSIS RAW DATA (CONTINUED)

GC RUN NO.	ANALYSIS NO.	EMISSIONS SOURCE	GC PEAK AREAS				
			CO2	H2	N2	METHANE	CO
229	0622-06002	BACKGROUND, NH3	†	†	7.17E+07	†	†
230	0629-003	CALGAS, CT2112	7.22E+06	1.09E+06	5.39E+07	2.36E+04	1.30E+07
231	062221-01503	RND 21 SPENT CASING, H2S	5.75E+05	8.50E+04	6.26E+07	1.28E+04	1.42E+06
232	062222-02503	RND 22 SPENT CASING, H2S	6.48E+05	1.13E+05	6.30E+07	1.35E+04	1.59E+06
233	062223-03503	RND 23 SPENT CASING, H2S	5.59E+05	7.15E+04	6.28E+07	9.22E+03	1.59E+06
234	0622-06003	BACKGROUND, H2S	6.41E+05	†	6.53E+07	†	†
237	0629-004	CALGAS, CT2112	7.25E+06	1.09E+06	5.42E+07	3.17E+04	1.31E+07
239	0630-001	CALGAS, CT2112	7.29E+06	1.10E+06	5.54E+07	2.38E+04	1.33E+07
240	062221-01504	RND 21 SPENT CASING, NOx	4.73E+05	8.31E+04	6.13E+07	9.40E+03	1.44E+06
241	062222-02504	RND 22 SPENT CASING, NOx	5.11E+05	1.06E+05	6.03E+07	9.23E+03	1.53E+06
242	062223-03504	RND 23 SPENT CASING, NOx	3.91E+05	6.06E+04	6.26E+07	8.71E+03	1.17E+06
243	0622-06004	BACKGROUND, NOx	†	†	6.78E+07	†	†
246	0630-002	CALGAS, CT2112	7.17E+06	1.09E+06	5.40E+07	2.88E+04	1.30E+07
247	0630-003	CALGAS, CT2112	7.37E+06	1.08E+06	5.52E+07	2.54E+04	1.33E+07
248	062221-PC301	RND 21-BREECH, PAH	1.69E+06	3.20E+05	6.08E+07	2.84E+04	3.90E+06
249	062222-PC302	RND 22 BREECH, PAH	1.51E+06	3.17E+05	6.11E+07	3.72E+04	4.37E+06
250	062223-PC303	RND 23 BREECH, PAH	3.38E+06	7.33E+05	5.47E+07	6.65E+04	9.28E+06
251	062224-PC304	RND 24 BREECH, PAH	3.11E+06	6.85E+05	5.52E+07	7.19E+04	8.19E+06
252	062221-TC305-SC	RND 21 SPENT CASING, TENAX	4.73E+05	4.97E+04	6.49E+07	†	8.27E+05
253	0630-004	CALGAS, CT2112	7.49E+06	1.09E+06	5.55E+07	2.51E+04	1.34E+07
254	062222-TC306-SC	RND 22 SPENT CASING, TENAX	6.26E+05	8.95E+04	6.42E+07	1.07E+04	1.64E+06
255	062223-TC307-SC	RND 23 SPENT CASING, TENAX	3.75E+05	3.43E+04	6.55E+07	†	5.54E+05
256	0630-005	CALGAS, CT2112	7.40E+06	1.09E+06	5.52E+07	3.54E+04	1.33E+07
257	0701-001	CALGAS, CT2112	7.58E+06	1.10E+06	5.60E+07	2.28E+04	1.36E+07
258	0622-BKGD-TC308	BACKGROUND, TENAX	2.35E+05	†	6.65E+07	†	9.12E+04
263	0623-BKGD-TC316	BACKGROUND, TENAX	3.85E+05	2.86E+04	6.61E+07	†	8.64E+05
264	0701-002	CALGAS, CT2112	7.43E+06	1.13E+06	5.56E+07	2.23E+04	1.34E+07

† BELOW DETECTION LIMIT (1.00E+02)

TABLE 16. GUN, M68; BORE 105 MM; PROPELLANT, M30 - INORGANIC GASES AND METHANE CONCENTRATIONS

GC RUN NO.	ANALYSIS NO.	EMISSIONS SOURCE	CONCENTRATION (VOL%)				
			CO2	H2	N2	METHANE	CO
=====	=====	=====	=====	=====	=====	=====	=====
109	052000-06-001	BACKGROUND, HCN	†	†	77.12	†	†
118	052000-06-002	BACKGROUND, NH3	†	†	76.63	†	†
80	052000-06-003	BACKGROUND, H2S	†	†	74.74	†	†
127	052000-06-004	BACKGROUND, NOx	†	†	80.31	†	†
69	052010A-01-001	RND 10(A) COLD,BREECH, HCN	9.10	14.37	51.11	0.106	17.83
113	052010A-01-002	RND 10(A) COLD,BREECH, NH3	7.62	11.96	54.88	0.100	16.06
75	052010A-01-003	RND 10(A) COLD,BREECH, H2S	6.79	10.61	56.73	0.082	13.14
122	052010A-01-004	RND 10(A) COLD,BREECH, NOx	7.64	12.46	51.08	0.105	17.21
105	052010B-02-001	RND 10(B) COLD,BREECH, HCN	6.48	11.30	56.49	0.091	14.84
114	052010B-02-002	RND 10(B) COLD,BREECH, NH3	7.63	12.10	52.84	0.102	16.26
76	052010B-02-003	RND 10(B) COLD,BREECH, H2S	8.09	13.17	52.60	0.087	15.75
123	052010B-02-004	RND 10(B) COLD,BREECH, NOx	7.18	12.37	53.36	0.104	16.30
106	052010C-03-001	RND 10(C) COLD,BREECH, HCN	5.09	9.48	60.35	0.079	12.17
115	052010C-03-002	RND 10(C) COLD,BREECH, NH3	5.17	9.61	60.22	0.076	11.38
77	052010C-03-003	RND 10(C) COLD,BREECH, H2S	4.49	7.96	62.97	0.061	9.13
124	052010C-03-004	RND 10(C) COLD,BREECH, NOx	4.84	9.67	59.79	0.064	11.73
110	052011-07-501	RND 11 HOT,SPENT CASING, HCN	6.19	12.32	54.23	0.136	16.19
119	052011-07-502	RND 11 HOT,SPENT CASING, NH3	6.93	12.88	53.54	0.152	16.99
83	052011-07-503	RND 11 HOT,SPENT CASING, H2S	6.97	13.96	54.23	0.138	17.43
128	052011-07-504	RND 11 HOT,SPENT CASING, NOx	6.06	13.01	50.61	0.136	15.71
111	052012-08-501	RND 12 HOT,SPENT CASING, HCN	6.13	10.73	56.90	0.162	16.37
120	052012-08-502	RND 12 HOT,SPENT CASING, NH3	6.52	10.89	55.47	0.162	16.40
84	052012-08-503	RND 12 HOT,SPENT CASING, H2S	6.46	11.21	55.66	0.148	16.53
129	052012-08-504	RND 12 HOT,SPENT CASING, NOx	5.85	10.66	52.55	0.277	15.34
107	052013-04-001	RND 13 HOT,BREECH, HCN	5.11	11.39	58.21	0.138	13.31
116	052013-04-002	RND 13 HOT,BREECH, NH3	5.68	10.91	57.63	0.142	13.53
78	052013-04-003	RND 13 HOT,BREECH, H2S	6.00	11.90	56.53	0.140	13.15
125	052013-04-004	RND 13 HOT,BREECH, NOx	5.11	10.55	56.60	0.139	13.24
108	052015-05-001	RND 15 HOT,BREECH, HCN	1.86	3.91	69.98	0.043	4.92
117	052015-05-002	RND 15 HOT,BREECH, NH3	2.20	4.08	70.19	0.029	4.98
79	052015-05-003	RND 15 HOT,BREECH, H2S	2.41	4.09	68.05	0.037	4.87
126	052015-05-004	RND 15 HOT,BREECH, NOx	1.85	3.89	69.20	0.035	4.80

TABLE 16. GUN, M68; BORE 105 MM; PROPELLANT, M30 - INORGANIC GASES AND METHANE CONCENTRATIONS (CONTINUED)

GC RUN NO.	ANALYSIS NO.	EMISSIONS SOURCE	CONCENTRATION (VOL%)				
			CO2	H2	N2	METHANE	CO
220	0622-06001	BACKGROUND, HCN	†	†	77.40	†	†
229	0622-06002	BACKGROUND, NH3	†	†	85.02	†	†
234	0622-06003	BACKGROUND, H2S	0.70	†	77.48	†	†
243	0622-06004	BACKGROUND, NOx	†	†	79.93	†	†
214	062221-01501	RND 21 SPENT CASING, HCN	0.51	0.86	74.96	0.0170	1.68
223	062221-01502	RND 21 SPENT CASING, NH3	0.74	0.86	74.51	0.0124	1.66
231	062221-01503	RND 21 SPENT CASING, H2S	0.63	0.92	74.48	0.0160	1.62
240	062221-01504	RND 21 SPENT CASING, NOx	0.52	0.92	72.19	0.0102	1.62
215	062222-02501	RND 22 SPENT CASING, HCN	0.57	1.49	74.31	0.0197	1.85
224	062222-02502	RND 22 SPENT CASING, NH3	0.80	1.17	74.42	0.0161	1.82
232	062222-02503	RND 22 SPENT CASING, H2S	0.71	1.21	74.73	0.0169	1.80
241	062222-02504	RND 22 SPENT CASING, NOx	0.56	1.17	71.03	0.0100	1.72
216	062223-03501	RND 23 SPENT CASING, HCN	0.45	0.73	75.10	†	1.63
226	062223-03502	RND 23 SPENT CASING, NH3	0.70	0.78	74.90	0.0142	1.57
233	062223-03503	RND 23 SPENT CASING, H2S	0.61	0.73	74.51	0.0115	1.58
242	062223-03504	RND 23 SPENT CASING, NOx	0.43	0.67	73.80	0.0094	1.32

† = BELOW DETECTION LIMIT

TABLE 17. GUN, M68; BORE, 105 MM; PROPELLANT, M30 - HCN ANALYSIS:
APPARENT TEMPORAL EFFECTS ON RAW DATA

			(1) TOTAL CYANIDE ANALYSIS (mg/L)			[C]/[B]
SAMPLE NO.	SAMPLING DATE	EMISSIONS SOURCE	[A]	[B]	[C]	
			ANALYSIS DATE: 6/08/88]	ANALYSIS DATE: 7/15/88]	REANALYSIS DATE: 8/04/88]	
=====	=====	=====	=====	=====	=====	=====
0520-01001	5/20/88	BREECH	0.79			
0520-02001	5/20/88	BREECH	0.23			
0520-03001	5/20/88	BREECH	0.13			
0520-04001	5/20/88	BREECH	0.25			
0520-05001	5/20/88	BREECH	0.17			
0520-06001	5/20/88	BACKGROUND	0.10			
0520-07001	5/20/88	SPENT CASING	0.10			
0520-08001	5/20/88	SPENT CASING	0.11			
0622-01501	6/22/88	SPENT CASING		0.05	0.10	2.00
0622-02501	6/22/88	SPENT CASING		1.94	0.10	0.05
0622-03501	6/22/88	SPENT CASING		0.10	0.33	3.30
0622-06001	6/22/88	BACKGROUND		2.78	0.10	0.04

(1) SOLUTION VOLUME = 50 ml
BELOW DETECTION LIMIT (0.1 mg/L)

TABLE 18. GUN, M68; BORE, 105 MM; PROPELLANT, M30
NH3 ANALYSIS: APPARENT TEMPORAL EFFECTS ON RAW DATA

					(1)	
					AMMONIA-N (ag/L)	
SAMPLE NO.	SAMPLING DATE	EMISSIONS SOURCE	[A]	[B]	[C]	[C]/[B]
			[ANALYSIS DATE: 6/08/88]	[ANALYSIS DATE: 7/15/88]	[REANALYSIS DATE: 8/04/88]	
			=====	=====	=====	=====
0520-(10A)-01001	5/20/88	BREECH	13.2			
0520-(10B)-02001	5/20/88	BREECH	18.7			
0520-(10C)-03001	5/20/88	BREECH	13.7			
0520-(13)-04001	5/20/88	BREECH	24.6			
0520-(15)-05001	5/20/88	BREECH	14.4			
0520-06001	5/20/88	BACKGROUND	0.2			
0520-(11)-07001	5/20/88	SPENT CASING	22.5			
0520-(12)-08001	5/20/88	SPENT CASING	19.1			
0622-01501	6/22/88	SPENT CASING		4.1	3.6	0.9
0622-02501	6/22/88	SPENT CASING		4.6	3.4	0.7
0622-03501	6/22/88	SPENT CASING		4.5	2.3	0.6
0622-06001	6/22/88	BACKGROUND		0.2	0.2	1.0

(1) SOLUTION VOLUME = 50 ml
DETECTION LIMIT = 0.1 ag/L

TABLE 19. GUN, M68; BORE, 105 MM; PROPELLANT, M30
- H₂S ANALYSIS RAW DATA

SAMPLE NO.	EMISSION SOURCE	S ²⁻ (from H ₂ S) (micrograms)
=====	=====	=====
0622-(21)-01503	SPENT CASING	‡
0622-(22)-02503	SPENT CASING	‡
0622-(23)-03503	SPENT CASING	‡

‡ = BELOW DETECTION LIMIT (0.4 micrograms)

TABLE 20. GUN, M68; BORE, 105 MM; PROPELLANT, M30
- NO_x AND SO_x ANALYSIS RAW DATA

ANALYSIS NO.	EMISSIONS SOURCE	SAMPLE SOURCE	(1) TOTAL SAMPLE CONCENTRATION (micrograms/L AIR)	
			NO _x	SO _x
			=====	=====
0719-12	052010-01004,RND 10	BREECH	31.0	129.7
0719-13	052010-02004,RND 10	BREECH	35.1	86.9
0719-14	052010-03004,RND 10	BREECH	24.3	65.5
0719-15	052013-04004,RND 13	BREECH	29.7	82.9
0719-16	052015-05004,RND 15	BREECH	10.8	22.7
0719-17	0520-06004,BACKGROUND	BACKGROUND	8.1	18.7
0720-3	052011-07504,RND 11	SPENT CASING	28.3	701.7
0720-5	052012-08504,RND 12	SPENT CASING	29.3	2085.2
0720-15	0622-01504,RND 1	SPENT CASING	10.8	18.7
0720-17	0622-02504,RND 2	SPENT CASING	16.2	42.8
0720-21	0622-06004,BACKGROUND	BACKGROUND	8.1	7.4

(1) = DETECTION LIMIT, DL(NO_x) = 0.1 micrograms/L AIR
DL(SO_x) = 0.1 micrograms/L AIR

TABLE 21. GUN, M68; BORE, 105 MM; PROPELLANT, M30 - MASS CONCENTRATION OF INORGANIC GAS EMISSIONS

GC RUN NO.	SAMPLE NO.	EMISSIONS SOURCE	SAMPLE VOLUME (ml)	MASS CONCENTRATION OF GASES (micrograms/Liter)					
				CO	HCN	NH ₃	H ₂ S	NO ₂	SO ₂
109	052000-06-001	BACKGROUND, HCN	1024	0	2.5				
118	052000-06-002	BACKGROUND, NH ₃	1024	0		11.9			
80	052000-06-003	BACKGROUND, H ₂ S	1024	0			11		
127	052000-06-004	BACKGROUND, NO _x	1024	0				8.1	18.7
69	052010A-01-001	RND 10(A) COLD,BREECH, HCN	1024	206,517	40.1				
113	052010A-01-002	RND 10(A) COLD,BREECH, NH ₃	1024	185,974		783.7			
75	052010A-01-003	RND 10(A) COLD,BREECH, H ₂ S	1024	152,222			11		
122	052010A-01-004	RND 10(A) COLD,BREECH, NO _x	1024	199,350				51.0	129.7
105	052010B-02-001	RND 10(B) COLD,BREECH, HCN	1024	171,875	11.7				
114	052010B-02-002	RND 10(B) COLD,BREECH, NH ₃	1024	188,402		1110.2			
76	052010B-02-003	RND 10(B) COLD,BREECH, H ₂ S	1024	182,446			11		
123	052010B-02-004	RND 10(B) COLD,BREECH, NO _x	1024	188,862				55.1	56.9
106	052010C-03-001	RND 10(C) COLD,BREECH, HCN	1024	140,947	6.6				
115	052010C-03-002	RND 10(C) COLD,BREECH, NH ₃	1024	134,160		813.4			
77	052010C-03-003	RND 10(C) COLD,BREECH, H ₂ S	1024	105,721			11		
124	052010C-03-004	RND 10(C) COLD,BREECH, NO _x	1024	135,867				24.3	65.5
110	052011-07-501	RND 11 HOT,SPENT CASING, HCN	1024	187,510	5.1				
119	052011-07-502	RND 11 HOT,SPENT CASING, NH ₃	1024	196,777		1335.8			
83	052011-07-503	RND 11 HOT,SPENT CASING, H ₂ S	1024	201,844			11		
128	052011-07-504	RND 11 HOT,SPENT CASING, NO _x	1024	131,957				28.3	701.7
111	052012-08-501	RND 12 HOT,SPENT CASING, HCN	1024	189,610	5.6				
120	052012-08-502	RND 12 HOT,SPENT CASING, NH ₃	1024	189,912		1134.0			
84	052012-08-503	RND 12 HOT,SPENT CASING, H ₂ S	1024	191,498			11		
129	052012-08-504	RND 12 HOT,SPENT CASING, NO _x	1024	177,717				28.3	2085.2
107	052013-04-001	RND 13 HOT,BREECH, HCN	1024	154,140	12.7				
116	052013-04-002	RND 13 HOT,BREECH, NH ₃	1024	156,700		1460.5			
78	052013-04-003	RND 13 HOT,BREECH, H ₂ S	1024	152,370			11		
125	052013-04-004	RND 13 HOT,BREECH, NO _x	1024	153,326				29.7	82.9
108	052015-05-001	RND 15 HOT,BREECH, HCN	1024	56,978	8.6				
117	052015-05-002	RND 15 HOT,BREECH, NH ₃	1024	56,535		854.9			
79	052015-05-003	RND 15 HOT,BREECH, H ₂ S	1024	56,373			11		
126	052015-05-004	RND 15 HOT,BREECH, NO _x	1024	55,652				10.8	22.7

TABLE 21. GUN, M68; BORE, 105 MM; PROPELLANT, M30 - MASS CONCENTRATION OF INORGANIC GAS EMISSIONS (CONTINUED)

GC RUN NO.	SAMPLE NO.	EMISSIONS SOURCE	SAMPLE VOLUME (ml)	MASS CONCENTRATION OF GASES (micrograms/Liter)					
				CO	HCN	NH3	H2S	NO ₂	SO ₂
220	0622-06001	BACKGROUND, HCN	1024	0	2.5				
229	0622-06002	BACKGROUND, NH3	1024	0		11.9			
234	0622-06003	BACKGROUND, H2S	1024	0			†		
243	0622-06004	BACKGROUND, NO _x	1024	0				8.1	7.4
214	062221-01501	RND 21 SPENT CASING, HCN	1024	18,210	5.1				
223	062221-01502	RND 21 SPENT CASING, NH3	1024	17,976		213.7			
231	062221-01503	RND 21 SPENT CASING, H2S	1024	17,512			†		
240	062221-01504	RND 21 SPENT CASING, NO _x	1024	17,592				10.9	18.7
215	062222-02501	RND 22 SPENT CASING, HCN	1024	20,084	5.1				
224	062222-02502	RND 22 SPENT CASING, NH3	1024	19,762		201.9			
232	062222-02503	RND 22 SPENT CASING, H2S	1024	19,530			†		
241	062222-02504	RND 22 SPENT CASING, NO _x	1024	18,696				16.2	42.9
216	062223-03501	RND 23 SPENT CASING, HCN	1024	17,613	16.7				
226	062223-03502	RND 23 SPENT CASING, NH3	1024	17,014		166.2			
233	062223-03503	RND 23 SPENT CASING, H2S	1024	17,086			†		
242	062223-03504	RND 23 SPENT CASING, NO _x	1024	14,256				††	††

† = BELOW DETECTION LIMIT

†† = COLLECTED BUT NOT ANALYZED.

TABLE 22. GUN, M68; BORE, 105 MM; PROPELLANT, M30 - RATIO OF INORGANIC GASES AND METHANE EMISSION CONCENTRATIONS TO CARBON MONOXIDE CONCENTRATION

GC RUN NO.	SAMPLE NO.	EMISSIONS COLLECTED	MOLES OF SPECIES PER MOLES OF CARBON MONOXIDE (1)							
			CO2	H2	METHANE	HCN	NH3	H2S	NO ₂	SO ₂
69	052010A-01-001	RND 10(A) COLD,BREECH, HCN				1.88E-04				
113	052010A-01-002	RND 10(A) COLD,BREECH, NH3					6.83E-03			
75	052010A-01-003	RND 10(A) COLD,BREECH, H2S						11		
122	052010A-01-004	RND 10(A) COLD,BREECH, NOx							5.19E-05	1.6
		AVG	4.86E-01	7.77E-01	6.12E-03					
105	052010B-02-001	RND 10(B) COLD,BREECH, HCN				5.51E-05				
114	052010B-02-002	RND 10(B) COLD,BREECH, NH3					9.59E-03			
76	052010B-02-003	RND 10(B) COLD,BREECH, H2S						11		
123	052010B-02-004	RND 10(B) COLD,BREECH, NOx							6.46E-05	1.0
		AVG	4.65E-01	7.75E-01	6.06E-03					
106	052010C-03-001	RND 10(C) COLD,BREECH, HCN				2.98E-05				
115	052010C-03-002	RND 10(C) COLD,BREECH, NH3					9.83E-03			
77	052010C-03-003	RND 10(C) COLD,BREECH, H2S						11		
124	052010C-03-004	RND 10(C) COLD,BREECH, NOx							5.39E-05	1.0
		AVG	4.42E-01	8.26E-01	6.31E-03					
107	052011-07-501	RND 13 HOT,BREECH, HCN				6.82E-05				
116	052011-07-502	RND 13 HOT,BREECH, NH3					1.52E-02			
78	052011-07-503	RND 13 HOT,BREECH, H2S						11		
125	052011-07-504	RND 13 HOT,BREECH, NOx							6.36E-05	1.2
		AVG	4.12E-01	8.41E-01	1.05E-02					
108	052012-08-501	RND 15 HOT,BREECH, HCN				1.11E-04				
117	052012-08-502	RND 15 HOT,BREECH, NH3					2.45E-02			
79	052012-08-503	RND 15 HOT,BREECH, H2S						11		
126	052012-08-504	RND 15 HOT,BREECH, NOx							2.15E-05	2.1
		AVG	4.27E-01	8.20E-01	7.37E-03					
110	052013-04-001	RND 11 HOT,SPENT CASING, HCN				1.40E-05				
119	052013-04-002	RND 11 HOT,SPENT CASING, NH3					1.11E-02			
83	052013-04-003	RND 11 HOT,SPENT CASING, H2S						11		
128	052013-04-004	RND 11 HOT,SPENT CASING, NOx							5.02E-05	1.0
		AVG	3.94E-01	7.87E-01	8.48E-03					
111	052015-05-001	RND 12 HOT,SPENT CASING, HCN				1.66E-05				
120	052015-05-002	RND 12 HOT,SPENT CASING, NH3					9.72E-03			
84	052015-05-003	RND 12 HOT,SPENT CASING, H2S						11		
129	052015-05-004	RND 12 HOT,SPENT CASING, NOx							5.14E-05	3.3
		AVG	3.86E-01	6.73E-01	1.17E-02					
214	062221-01501	RND 21 SPENT CASING, HCN				1.39E-04				
223	062221-01502	RND 21 SPENT CASING, NH3					1.12E-02			
231	062221-01503	RND 21 SPENT CASING, H2S						1		
240	062221-01504	RND 21 SPENT CASING, NOx							6.93E-05	2.3
		AVG	3.66E-01	5.41E-01	8.44E-03					

TABLE 22. GUN, M68; BORE, 105 MM; PROPELLANT, M30 - RATIO OF INORGANIC GASES AND METHANE EMISSION CONCENTRATIONS TO CARBON MONOXIDE CONCENTRATION (CONTINUED)

			MOLES OF SPECIES PER MOLES OF CARBON MONOXIDE (1)							
GC RUN NO.	SAMPLE NO.	EMISSIONS COLLECTED	CO2	H2	METHANE	HCN	NH3	H2S	NO ₂	SO ₂
=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
215	062222-02501	RND 22 SPENT CASING, HCN				1.26E-04				
224	062222-02502	RND 22 SPENT CASING, NH3					9.61E-03			
232	062222-02503	RND 22 SPENT CASING, H2S						*		
241	062222-02504	RND 22 SPENT CASING, NOx							1.98E-04	
		AVG	3.16E-01	6.99E-01	8.66E-03					
216	062223-03501	RND 23 SPENT CASING, HCN				8.06E-04				
226	062223-03502	RND 23 SPENT CASING, NH3					9.07E-03			
233	062223-03503	RND 23 SPENT CASING, H2S						*		
242	062223-03504	RND 23 SPENT CASING, NOx							**	
		AVG	3.60E-01	4.80E-01	5.88E-03					
BREECH 6/22/88 (5)			AVG	4.46E-01	8.08E-01	7.27E-03	9.04E-05	1.32E-02	**	5.12E-05
			RSD	0.067	0.037	0.260	0.587	0.532		0.533
SPENT CASING 6/22/88 (5)			AVG	3.74E-01	6.36E-01	8.63E-03	2.21E-04	1.01E-02	*	9.15E-05
			RSD	0.039	0.195	0.239	1.509	0.094		0.739

* = BELOW DETECTION LIMIT

** = COLLECTED BUT NOT ANALYZED.

TABLE 23. GUN, M68; BORE, 105 MM; PROPELLANT, M30
- PAH ANALYSIS RAW DATA

MASS CONCENTRATION OF PAH IN COLLECTED SAMPLES (micrograms/Liter)												
ANALYSIS NO.	EMISSIONS SOURCE	SAMPLE VOLUME (LITERS)	PAHs									
			PHEN- ANTHRENE	FLUOR- ANTHRENE	PYRENE	BENZ-a- ANTHRACENE	CHRYSENE	FLUORANTHRENE	BENZ-k- FLUORANTHRENE	BENZ-a- PYRENE	BENZ-ghi- PERLENE	
2-P02	RND 2, PAH	30	7.30E-04	3.14E-05	1.52E-03	2.44E-03	7.47E-05	1.72E-04	8.07E-05	2.55E-04	1.45E-04	3.60E-04
2-P04	RND 5, PAH	30	1.01E-03	2.49E-05	1.69E-03	2.82E-03	2.75E-04	4.27E-04	1.19E-04	6.87E-04	4.13E-04	1.07E-03
2-P06	BACKGROUND, PAH	30	7.00E-04	2.77E-05	5.10E-05	6.70E-05	1.98E-05	3.13E-05	3.73E-05	8.90E-05	7.77E-05	1.26E-04
2-P8	BLANK, PAH (PUF ONLY)	0	1.32E-05	†	7.90E-05	4.37E-05	5.33E-06	1.13E-05	1.07E-05	3.43E-05	2.40E-05	6.70E-05
4-301	BREECH, RND21	20	2.23E-02	7.60E-04	1.09E-03	5.15E-04	1.15E-04	1.81E-04	9.00E-05	5.45E-04	3.20E-04	8.10E-04
4-302	BREECH, RND22	20	†	†	3.42E-04	4.08E-04	2.54E-04	1.55E-04	8.70E-05	3.75E-04	2.58E-04	5.40E-04
4-303	BREECH, RND23	20	†	†	1.77E-04	4.95E-05	2.42E-04	1.41E-04	1.45E-05	2.35E-05	8.00E-06	5.40E-04
4-304	BREECH, RND24	20	1.03E-02	7.95E-04	†	3.15E-05	2.67E-04	1.81E-04	8.35E-05	4.29E-04	3.26E-04	9.00E-04

† = BELOW DETECTION LIMIT

TABLE 24. GUN, M68; BORE, 105 MM; PROPELLANT, M30 - RATIO OF PAH CONCENTRATIONS TO CARBON MONOXIDE CONCENTRATION

PAH ANALYSIS NO.	EMISSIONS SOURCE	MOLES OF PAH SPECIES PER MOLE OF CARBON MONOXIDE (1)									
		PHEN-ANTHRENE	FLUOR-ANTHRENE	PYRENE	BENZ-a-ANTHRACENE	CHRYSENE	FLUORANTHENE	BENZ-b-FLUORANTHENE	BENZ-k-FLUORANTHENE	BENZ-a-PYRENE	BENZ-ghi-PERLENE
2-P02	RND 2 BREECH, PAH	5.99E-11	7.45E-12	2.58E-09	4.18E-09	8.54E-11	2.19E-10	6.11E-11	2.34E-10	9.44E-11	3.02E-10
2-P04	RND 5 BREECH, PAH	5.86E-10	5.18E-12	2.71E-09	4.54E-09	3.73E-10	5.78E-10	1.08E-10	7.90E-10	4.44E-10	1.14E-09
4-301	BREECH, RND21, PAH	7.37E-08	2.51E-09	3.16E-09	1.50E-09	2.97E-10	4.67E-10	2.10E-10	.27E-09	7.47E-10	1.73E-09
4-302	BREECH, RND22, PAH	†	†	8.90E-10	1.06E-09	5.85E-10	3.58E-10	1.81E-10	7.82E-10	5.37E-10	1.03E-09
4-303	BREECH, RND23, PAH	†	†	2.16E-10	6.04E-11	2.62E-10	1.53E-10	1.42E-11	2.30E-11	7.82E-12	4.82E-10
4-304	BREECH, RND24, PAH	1.63E-09	1.25E-09	†	4.36E-11	3.28E-10	2.22E-10	9.26E-11	4.76E-10	3.62E-10	9.11E-10
MLOS BREECH PAH, AVG (6)		1.51E-08	6.27E-10	1.59E-09	1.90E-09	3.22E-10	3.33E-10	1.11E-10	5.96E-10	3.65E-10	9.31E-10
RSD		1.948	1.674	0.870	1.051	0.506	0.496	0.660	0.751	0.757	0.544

(1) LESS BACKGROUND LEVELS; (-) RATIOS INDICATE CONCENTRATIONS LESS THAN BACKGROUND.

TABLE 25. GUN, M68; BORE, 105 MM; PROPELLANT, M30
ALDEHYDE ANALYSIS RAW DATA

			MASS CONCENTRATION OF ALDEHYDES (1)							
			(micrograms/Liter)							
ANALYSIS NO	SAMPLE NO.	EMISSIONS SOURCE	FORM-ALDEHYDE	ACET-ALDEHYDE	ACROLEIN/ACETONE	PROPION-ALDEHYDE	CROTON-ALDEHYDE	ISOBUTYL-ALDEHYDE	BENZ-ALDEHYDE	HEXAN-ALDEHYDE
=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
2-1	0520-10A-01-005	ROUND 10[A], BREECH	0.78	6.41	10.84	0.66	0.40	4.10	5.01	0.41
2-2	0520-10B-02-005	ROUND 10[B], BREECH	1.18	6.45	7.26	0.66	†	3.13	4.45	0.22
2-4	0520-13A-04-005	ROUND 13, BREECH	0.71	4.47	19.43	0.62	0.21	2.29	2.62	0.27
2-5	0520-15-05-005	ROUND 15, BREECH	0.82	2.54	11.91	0.24	0.05	2.84	1.94	0.17
2-6	0520-00-06-005	BACKGROUND	3.77	0.22	0.67	0.14	†	0.12	0.09	0.13
2-7	0520-11-07-505	ROUND 11, SPENT CASING	3.57	3.59	35.25	1.76	0.90	3.27	1.46	1.55
2-8	0520-12-08-505	ROUND 12, SPENT CASING	1.74	1.93	6.78	0.59	0.26	1.35	0.81	0.29
4-1	0622-21-01-505	ROUND 21, SPENT CASING	†	0.17	13.87	†	†	†	0.54	0.08
4-2	0622-22-02-505	ROUND 22, SPENT CASING	8.11	0.64	12.60	†	†	0.11	0.47	0.18
4-3	0622-23-03-505	ROUND 23, SPENT CASING	1.32	3.25	15.72	0.52	†	0.91	0.89	0.50
4-6	0622-06-005	BACKGROUND	9.47	0.24	40.72	0.02	†	0.04	0.05	0.08

(1) AIR SAMPLE COLLECTED VOLUME = 1024 ml/EACH

† = BELOW DETECTION LIMIT (0.01 micrograms/L)

TABLE 26. GUN, M68; BORE, 105 MM; PROPELLANT, M30 - RATIO OF ALDEHYDE CONCENTRATION TO CARBON MONOXIDE CONCENTRATION

			MOLES OF ALDEHYDE PER MOLE OF CARBON MONOXIDE (1)									
ANALYSIS NO	SAMPLE NO.	EMISSIONS SOURCE	FORM-ALDEHYDE	ACET-ALDEHYDE	ACROLEIN/ACETONE	PROPION-ALDEHYDE	CROTON-ALDEHYDE	ISOBUTYL-ALDEHYDE	BENZ-ALDEHYDE	HEXAN-ALDEHYDE		
2-1	0520-10A-01005	ROUND 10(A), BREECH	2.40E-07	1.34E-06	1.72E-06	1.05E-07	5.26E-08	5.16E-07	4.34E-07	3.77E-08		
2-2	0520-10B-02005	ROUND 10(B), BREECH	4.00E-07	1.49E-06	1.27E-06	†	1.45E-09	4.36E-07	4.27E-07	2.24E-08		
2-4	0520-13A-04005	ROUND 13, BREECH	4.13E-07	1.78E-06	5.86E-06	1.86E-07	5.22E-08	5.50E-07	4.32E-07	4.72E-08		
2-5	0520-15-05005	ROUND 15, BREECH	1.38E-06	2.93E-06	1.04E-05	2.06E-07	3.54E-08	1.97E-06	9.36E-07	8.76E-08		
M105 BREECH ALDEHYDE, AVG (4)			6.08E-07	1.88E-06	4.82E-06	1.24E-07	3.55E-08	8.69E-07	5.56E-07	4.87E-08		
RSD			0.856	0.382	0.886	0.753	0.679	0.849	0.449	0.572		
2-7	0520-11-07505	ROUND 11, SPENT CASING	1.75E-06	1.20E-06	8.91E-06	4.44E-07	1.69E-07	6.57E-07	2.01E-07	2.28E-07		
2-8	0520-12-08505	ROUND 12, SPENT CASING	8.58E-07	6.51E-07	1.73E-06	1.50E-07	5.50E-08	2.73E-07	1.13E-07	4.32E-08		
4-1	0622-21-01505	ROUND 21, SPENT CASING	7.17E-08	8.31E-07	†	†	†	2.93E-08	1.10E-06	1.83E-07		
4-2	0522-22-02505	ROUND 22, SPENT CASING	5.35E-05	2.88E-06	†	†	2.83E-08	3.03E-07	8.85E-07	3.65E-07		
4-3	0622-23-03505	ROUND 23, SPENT CASING	9.77E-06	1.64E-05	6.03E-05	†	3.18E-08	2.76E-06	1.88E-06	1.34E-06		
M105 SPENT CASING ALDEHYDE, AVG (5)			1.32E-05	4.40E-06	1.42E-05	1.19E-07	6.09E-08	8.06E-07	8.35E-07	4.31E-07		
RSD			1.734	1.543	1.835	1.625	1.223	1.387	0.854	1.205		

(1) BACKGROUND NOT SUBTRACTED FROM ALDEHYDE LEVELS.

† = BELOW ANALYSIS LIMITS

TABLE 27. GUN, M68; BORE, 105 MM; PROPELLANT, M30
- VOLATILE ORGANIC GASES, GC/MS RAW DATA

COLLECTED VOLATILE ORGANIC GASES (micrograms)											
GC/MS ANALYSIS NO.	SAMPLE NO.	EMISSIONS SOURCE	SAMPLE VOLUME (LITER)	BENZENE	ACRYLO- NITRILE	ETHYL BENZENE	TOLUENE	PYRIDINE	STYRENE	CYANO- BENZENE	NAPHTHALENE
B6SN08	0520-07-T306	ROUND 10(A) [FT], BREECH	0.281	20.089 #	4.943 #	3.168	6.397	2.757	6.648	31.483 #	1.128
B6SN10	0520-07-T316	ROUND 10(A) [BK], BREECH	0.281	0.028	0.014	0.019	0.105	0.022	0.010	0.024	0.007
B6SN09	0520-18-T312	ROUND 14, SPENT CASING	0.281	6.777 #	0.490	0.859	0.897	0.222	0.664	1.250	0.303
B6SN11	0520-14-T309	ROUND 15(B), BREECH	0.281	1.025 #	0.060	0.033	0.242	0.115	0.153	1.160	0.290
B6SN12	0520-17-T311	ROUND 13, SPENT CASING	0.281	4.597 #	0.919 #	0.934	0.932	0.270	0.896	1.293	0.318
B6SN15	0520-23-T315	BLANK	. #	0.014	0.006	0.008	0.046	0.024	#	0.013	#
B6SN40	0622-07-T308	ROUND 23 [BK], SPENT CASING	0.281	0.042	0.013	0.022	0.151	#	0.006	0.051	#

ESTIMATED FROM SATURATED PEAK AREA.

BELOW DETECTION LIMIT (0.005 micrograms/SAMPLE)

TABLE 28. GUN, M68; BORE, 105 MM; PROPELLANT, M30
- CONCENTRATION OF VOLATILE ORGANIC GASES

SAMPLE NO.	EMISSIONS SOURCE	CONCENTRATION OF COLLECTED EMISSIONS (1) (microgram/Liter)							
		BENZENE	ACRYLO-NITRILE	ETHYL BENZENE	TOLUENE	PYRIDINE	STYRENE	CYANO-BENZENE	NAPHTHALENE
0520-07-T306F	ROUND 10(A) [FT], BREECH	71.30	17.55	11.13	22.28	9.71	23.60	111.99	40.02
0520-07-T316B	ROUND 10(A) [BK], BREECH	-0.09	0.01	-0.08	-0.11	-0.02	-0.03	0.03	0.14
0520-14-T309	ROUND 15(B), BREECH	23.93	1.71	2.91	2.70	0.69	2.30	4.40	10.57
0520-17-T311	ROUND 13, SPENT CASING	3.46	0.18	-0.03	0.38	0.31	0.48	4.08	10.20
0520-18-T312	ROUND 14, SPENT CASING	16.17	3.23	3.18	2.93	0.86	3.13	4.55	11.22
0622-07-T308B	ROUND 23 [BK], SPENT CASING	-0.04	0.01	-0.07	0.05	-0.08	-0.04	0.13	0.07

(1) LESS BLANK CONCENTRATION

(2) [FT] = FRONT COLLECTOR AND [BK] = BACK COLLECTOR OF A TANDUM PAIR.

TABLE 29. GUN, M68; BORE, 105 MM; PROPELLANT, M30 - RATIO OF VOLATILE ORGANIC GASES CONCENTRATIONS TO CARBON MONOXIDE CONCENTRATION

			MOLES OF SPECIES PER MOLE OF CARBON MONOXIDE IN SAMPLE (1)									
[2]			BENZENE	ACRYLO- NITRILE	ETHYL BENZENE	TOLUENE	PYRIDINE	STYRENE	CYANO- BENZENE	NAPHTHALENE		
SAMPLE NO.	EMISSIONS SOURCE											
0520-07-T306F	ROUND 10(A) [FT], BREECH	&	0.000190	0.000069	0.000022	0.000050	0.000026	0.000047	0.000226	0.000095		
0520-07-T316B	ROUND 10(A) [BK], BREECH		-0.000000	0.000000	-0.000000	-0.000000	-0.000000	-0.000000	0.000000	0.000000		
0520-14-T309	ROUND 15(B), BREECH	&	0.000137	0.000014	0.000012	0.000013	0.000004	0.000010	0.000019	0.000027		
0520-17-T311	ROUND 13, SPENT CASING	&	0.000010	0.000001	-0.000000	0.000001	0.000001	0.000001	0.000009	0.000017		
0520-18-T312	ROUND 14, SPENT CASING	&	0.000045	0.000013	0.000006	0.000007	0.000002	0.000006	0.000010	0.000019		
0622-07-T308B	ROUND 23 [BK], SPENT CASING		-0.000002	0.000001	-0.000003	0.000002	-0.000005	-0.000002	0.000005	0.000002		
BREECH			5/20/88	AVG (2)	1.64E-04	4.17E-05	1.71E-05	3.18E-05	1.48E-05	2.86E-05	1.27E-04	3.11E-05
				RSD	0.230	0.926	0.397	0.830	1.937	0.925	1.195	0.766
SPENT CASING			5/20/88	AVG (2)	2.72E-05	6.95E-06	3.21E-06	3.76E-06	1.62E-06	3.75E-06	9.03E-06	1.81E-05
				RSD	0.917	1.258	1.437	1.083	0.659	1.937	0.979	0.367

(1) LESS BACKGROUND LEVELS

(2) ([FT] = FRONT COLLECTOR AND [BK] = BACK COLLECTOR OF A TANDUM SET.)

& = SAMPLES USED FOR AVERAGING.

DATA FOR THE 155 MM CALIBER, M199 GUN
WITH M30A1 PROPELLANT
(BREECH SAMPLES)

TABLE 30. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- INORGANIC GASES AND METHANE ANALYSIS RAW DATA

GC RUN NO.	ANALYSIS NO.	EMISSIONS SOURCE	GC PEAK AREAS				
			CO2	H2	N2	METHANE	CO
444	1006-001	CALGAS, CT2112	7.55E+06	1.18E+06	6.17E+07	3.04E+04	1.53E+07
445	1006-002	CALGAS, CT2112	7.56E+06	1.25E+06	6.17E+07	3.02E+04	1.53E+07
446	1006-003	CALGAS, CT2112	7.61E+06	1.27E+06	6.17E+07	2.99E+04	1.54E+07
447	1006-004	CALGAS, CT2112	7.68E+06	1.29E+06	6.21E+07	3.08E+04	1.55E+07
448	1004-01005	RND 2 BREECH, ALDEHYDE	2.16E+06	9.36E+05	5.45E+07	5.06E+05	9.28E+06
449	1004-02005	RND 4 BREECH, ALDEHYDE	3.11E+06	9.65E+05	5.13E+07	6.21E+05	1.12E+07
450	1006-005	CALGAS, CT2112	7.61E+06	1.29E+06	6.15E+07	3.17E+04	1.54E+07
451	1007-001	CALGAS, CT2112	7.75E+06	1.29E+06	6.26E+07	3.10E+04	1.55E+07
452	1007-002	CALGAS, CT2112	7.85E+06	1.32E+06	6.27E+07	3.09E+04	1.60E+07
453	1004-03005	RND 6 BREECH, ALDEHYDE	1.88E+06	1.03E+06	5.31E+07	4.39E+05	1.00E+07
454	1004-04005	RND 8 BREECH, ALDEHYDE	1.65E+06	7.51E+05	5.71E+07	3.31E+05	7.38E+06
455	1004-05005	RND 10 BREECH, ALDEHYDE	7.91E+05	6.62E+05	5.89E+07	3.02E+05	6.76E+06
456	1004-06005	BACKGROUND, ALDEHYDE	2.79E+04	†	6.76E+07	†	7.91E+04
457	1007-003	CALGAS, CT2112	7.63E+06	1.29E+06	6.14E+07	3.16E+04	1.53E+07
458	1004-01001	RND 2 BREECH, HCN	2.23E+06	1.00E+06	5.89E+07	5.54E+05	1.01E+07
459	1004-02001	RND 4 BREECH, HCN	3.32E+06	1.07E+06	5.60E+07	6.89E+05	1.24E+07
460	1004-03001	RND 6 BREECH, HCN	1.67E+06	1.11E+06	5.79E+07	5.01E+05	1.10E+07
461	1004-04001	RND 8 BREECH, HCN	7.96E+05	8.10E+05	6.24E+07	3.58E+05	7.96E+06
462	1004-04001(R)	RND 8 BREECH, HCN (RERUN)	8.08E+05	8.17E+05	6.27E+07	3.60E+05	8.00E+06
463	1004-05001	RND 10 BREECH, HCN	5.50E+05	7.22E+05	6.36E+07	3.27E+05	7.30E+06
464	1004-06001	BACKGROUND, HCN	†	†	7.31E+07	†	2.93E+04
465	1007-004	CALGAS, CT2112	7.52E+06	1.29E+06	6.06E+07	3.16E+04	1.53E+07
466	1004-01002	RND 2 BREECH, NH3	2.49E+06	1.01E+06	5.81E+07	5.47E+05	1.00E+07
467	1004-02002	RND 4 BREECH, NH3	3.62E+06	1.06E+06	5.53E+07	6.74E+05	1.21E+07
468	1004-03002	RND 6 BREECH, NH3	1.89E+06	1.05E+06	5.81E+07	4.73E+05	1.04E+07
469	1004-04002	RND 8 BREECH, NH3	1.13E+06	8.26E+05	6.19E+07	3.60E+05	9.01E+06
470	1004-05002	RND 10 BREECH, NH3	8.48E+05	7.23E+05	6.33E+07	3.26E+05	7.29E+06
471	1004-06001	BACKGROUND, NH3	3.07E+04	†	7.31E+07	†	1.24E+05
472	1007-005	CALGAS, CT2112	7.50E+06	1.28E+06	6.04E+07	2.99E+04	1.53E+07
474	1010-001	CALGAS, CT2112	7.53E+06	1.27E+06	6.00E+07	2.91E+04	1.50E+07
475	1010-002	CALGAS, CT2112	7.54E+06	1.28E+06	6.03E+07	2.87E+04	1.51E+07
476	1004-01003	RND 2 BREECH, H2S	2.44E+06	9.74E+05	5.77E+07	5.35E+05	9.77E+06
477	1004-02003	RND 4 BREECH, H2S	3.62E+06	1.05E+06	5.53E+07	6.73E+05	1.21E+07
478	1004-03003	RND 6 BREECH, H2S	2.11E+06	1.11E+06	5.62E+07	4.96E+05	1.07E+07
479	1004-04003	RND 8 BREECH, H2S	1.18E+06	8.06E+05	6.12E+07	3.55E+05	7.85E+06
480	1004-05003	RND 10 BREECH, H2S	8.79E+05	7.09E+05	6.25E+07	3.20E+05	7.12E+06
481	1004-06003	BACKGROUND, H2S	†	†	7.20E+07	†	†
482	1010-003	CALGAS, CT2112	7.34E+06	1.28E+06	5.92E+07	2.94E+04	1.50E+07
483	1004-01004	RND 2 BREECH, NOx	2.52E+06	9.83E+05	5.76E+07	5.43E+05	9.86E+06

TABLE 30. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- INORGANIC GASES AND METHANE ANALYSIS RAW DATA (CONTINUED)

GC RUN NO.	ANALYSIS NO.	EMISSIONS SOURCE	GC PEAK AREAS				
			CO2	H2	N2	METHANE	CO
484	1004-02004	RND 4 BREECH, NOx	3.59E+06	1.03E+06	5.47E+07	6.58E+05	1.17E+07
485	1010-004	CALGAS, CT2112	7.30E+06	1.26E+06	5.85E+07	2.99E+04	1.46E+07
486	1004-03004	RND 6 BREECH, NOx	2.16E+06	1.07E+06	5.63E+07	4.75E+05	1.04E+07
487	1004-04004	RND 8 BREECH, NOx	1.23E+06	8.00E+05	6.04E+07	3.51E+05	7.85E+06
488	1004-05004	RND 10 BREECH, NOx	9.31E+05	7.04E+05	6.13E+07	3.14E+05	7.09E+06
489	1004-06004	BACKGROUND, NOx	†	†	6.88E+07	†	1.10E+04
490	1010-005	CALGAS, CT2112	7.32E+06	1.26E+06	5.88E+07	2.89E+04	1.49E+07
491	1010-006	CALGAS, CT2112	7.31E+06	1.27E+06	5.87E+07	2.78E+04	1.49E+07
492	1011-001	CALGAS, CT2112	†	1.25E+06	6.03E+07	2.92E+04	1.49E+07
493	100412-PC301	RD 12 BREECH, PAH	8.09E+05	3.40E+05	6.78E+07	2.64E+05	3.50E+06
494	100414-PC302	RD 14 BREECH, PAH	1.32E+06	5.53E+05	6.44E+07	3.49E+05	6.01E+06
495	100423-PC303	RD 23 BREECH, PAH	1.41E+06	5.82E+05	6.38E+07	2.41E+05	6.72E+06
496	1011-002	CALGAS, CT2112	7.75E+06	1.30E+06	6.18E+07	3.04E+04	1.58E+07
497	100416-SC501	RD 16 BREECH, PARTICULATE SD4	2.49E+06	1.16E+06	5.79E+07	7.60E+05	1.23E+07
498	100419-SC502	RD 19 BREECH, PARTICULATE SD4	2.58E+06	9.35E+05	5.97E+07	1.11E+06	1.05E+07
499	100421-SC503	RD 21 BREECH, PARTICULATE SD4	2.46E+06	1.04E+06	5.91E+07	9.77E+05	1.06E+07
500	1011-003	CALGAS, CT2112	7.75E+06	1.22E+06	6.17E+07	3.11E+04	1.56E+07

† BELOW DETECTION LEVEL (1.00E+02)

TABLE 31. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- INORGANIC GASES AND METHANE CONCENTRATIONS

GC RUN NO.	ANALYSIS NO.	EMISSIONS SOURCE	EMISSION CONCENTRATIONS (VOL%)				
			CO2	H2	N2	METHANE	CO
464	1004-06001	BACKGROUND, HCN	†	†	77.01	†	0.03
471	1004-06001	BACKGROUND, NH3	0.03	†	77.09	†	0.12
481	1004-06003	BACKGROUND, H2S	†	†	78.36	†	†
489	1004-06004	BACKGROUND, NOx	†	†	75.34	†	0.01
458	1004-01001	RND 2 BREECH, HCN	2.36	9.34	62.09	0.5382	9.62
466	1004-01002	RND 2 BREECH, NH3	2.63	9.38	61.25	0.5317	9.73
476	1004-01003	RND 2 BREECH, H2S	2.66	9.24	63.24	0.5539	9.91
483	1004-01004	RND 2 BREECH, NOx	2.75	9.33	63.08	0.5620	9.91
459	1004-02001	RND 4 BREECH, HCN	3.50	10.01	59.01	0.6696	12.03
467	1004-02002	RND 4 BREECH, NH3	3.82	9.90	58.27	0.6552	11.76
477	1004-02003	RND 4 BREECH, H2S	3.96	9.97	60.55	0.6995	12.17
484	1004-02004	RND 4 BREECH, NOx	3.92	9.76	59.97	0.6810	11.74
460	1004-03001	RND 6 BREECH, HCN	1.76	10.38	60.98	0.4869	10.65
468	1004-03002	RND 6 BREECH, NH3	1.99	9.79	61.20	0.4602	10.06
478	1004-03003	RND 6 BREECH, H2S	2.31	10.49	61.60	0.5132	10.74
486	1004-03004	RND 6 BREECH, NOx	2.36	10.19	61.70	0.4914	10.40
461	1004-04001	RND 8 BREECH, HCN	0.84	7.55	65.78	0.3478	7.71
469	1004-04002	RND 8 BREECH, NH3	1.20	7.70	65.25	0.3496	7.76
479	1004-04003	RND 8 BREECH, H2S	1.29	7.65	67.02	0.3671	7.98
487	1004-04004	RND 8 BREECH, NOx	1.34	7.60	66.15	0.3629	7.88
463	1004-05001	RND 10 BREECH, HCN	0.58	6.73	67.02	0.3177	7.07
470	1004-05002	RND 10 BREECH, NH3	0.89	6.73	66.70	0.3165	7.06
480	1004-05003	RND 10 BREECH, H2S	0.96	6.73	68.49	0.3311	7.15
488	1004-05004	RND 10 BREECH, NOx	1.02	6.58	67.14	0.3252	7.12

† = BELOW DETECTION LIMIT

TABLE 32. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- HCN ANALYSIS RAW DATA

SAMPLE NO.	EMISSIONS SOURCE	(1)
		TOTAL CYANIDE ($\mu\text{g/L}$)
=====	=====	=====
1004-01001	BREECH	17.5
1004-02001	BREECH	19.9
1004-03001	BREECH	27.3
1004-04001	BREECH	14.2
1004-05001	BREECH	11.6
1004-06001	BACKGROUND	‡

(1) SOLUTION VOLUME = 50 ml

‡ = BELOW DETECTION LIMIT (0.1 $\mu\text{g/L}$)

TABLE 33. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- NH₃ ANALYSIS RAW DATA

SAMPLE NO.	EMISSIONS SOURCE	(1)
		AMMONIA-N ($\mu\text{g/L}$)
=====	=====	=====
1004-01002	BREECH	14.3
1004-02002	BREECH	20.4
1004-03002	BREECH	63.9
1004-04002	BREECH	48.5
1004-05002	BREECH	46.0
1004-06002	BACKGROUND	‡

(1) SOLUTION VOLUME = 50 ml

‡ = BELOW DETECTION LIMIT (0.1 $\mu\text{g/L}$)

TABLE 34. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- H₂S ANALYSIS RAW DATA

SAMPLE NO.	EMISSIONS SOURCE	S ²⁻ (from H ₂ S) (micrograms)
=====	=====	=====
1004-01003	BREECH	2630
1004-02003	BREECH	2500
1004-03003	BREECH	3220
1004-04003	BREECH	2950
1004-05003	BREECH	2680
1004-06003	BACKGROUND	†

† = BELOW DETECTION LIMIT (0.4 micrograms)

TABLE 35. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- NOX AND SOX ANALYSIS RAW DATA

ANALYSIS NO.	SAMPLE NO.	EMISSIONS SOURCE	(1) TOTAL SAMPLE CONCENTRATION (micrograms/L AIR)	
			NO ₃	SO ₂ ⁻
			=====	=====
1026-17	1004-01004	ROUND 2, BREECH GASES	16.0	10754.8
1026-18	1004-02004	ROUND 4, BREECH GASES	16.0	12476.8
1026-19	1004-03004	ROUND 6, BREECH GASES	31.9	18691.8
1026-20	1004-04004	ROUND 8, BREECH GASES	16.0	14026.6
1027-04	1004-05004	ROUND 10, BREECH GASES	47.9	14339.7
1027-05	1004-06004	BACKGROUND GASES	9.6	6.3
1027-08	1004-SF01	ROUND 16, BREECH AEROSOLS	15.2	7.4
1027-09	1004-SF02	ROUND 19, BREECH AEROSOLS	10.6	4.5
1027-10	1004-SF03	ROUND 21, BREECH AEROSOLS	10.6	6.0
1027-07	1004-SF04	BACKGROUND AEROSOLS	†	3.7
1027-06	1004-SF05	AEROSOLS, FILTER BLANK	†	3.0

(1) DETECTION LIMIT - DL(NO₃) = 0.1 micrograms/L AIR
- DL(SO₂⁻) = 0.1 micrograms/L AIR

† = BELOW DETECTION LIMIT

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TABLE 36. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1 - MASS CONCENTRATION OF COLLECTED INORGANIC GAS EMISSIONS

GC RUN NO.	SAMPLE NO.	EMISSIONS SOURCE	VOLUME (ml)	MASS CONCENTRATION OF GASES (micrograms/Liter)					
				CO	HCN	NH ₃	H ₂ S	NO ₂	SO ₂
464	1004-06001	BACKGROUND, HCN	1024	†	5				
471	1004-06001	BACKGROUND, NH ₃	1024	†		6			
481	1004-06003	BACKGROUND, H ₂ S	1024	†			†		
489	1004-06004	BACKGROUND, NO _x	1024	†				10	6
458	1004-01001	RND 2 BREECH, HCN	1024	117,411	909				
466	1004-01002	RND 2 BREECH, NH ₃	1024	116,288		969			
476	1004-01003	RND 2 BREECH, H ₂ S	1024	117,293			2,795		
483	1004-01004	RND 2 BREECH, NO _x	1024	118,397				16	11,013
459	1004-02001	RND 4 BREECH, HCN	1024	143,763	1,034				
467	1004-02002	RND 4 BREECH, NH ₃	1024	140,509		1,240			
477	1004-02003	RND 4 BREECH, H ₂ S	1024	145,415			2,657		
484	1004-02004	RND 4 BREECH, NO _x	1024	140,289				16	12,776
460	1004-03001	RND 6 BREECH, HCN	1024	127,276	1,418				
468	1004-03002	RND 6 BREECH, NH ₃	1024	120,236		3,885			
478	1004-03003	RND 6 BREECH, H ₂ S	1024	128,356			3,423		
486	1004-03004	RND 6 BREECH, NO _x	1024	124,262				33	19,140
461	1004-04001	RND 8 BREECH, HCN	1024	92,106	738				
469	1004-04002	RND 8 BREECH, NH ₃	1024	92,741		2,943			
479	1004-04003	RND 8 BREECH, H ₂ S	1024	94,218			3,156		
487	1004-04004	RND 8 BREECH, NO _x	1024	94,236				16	14,365
463	1004-05001	RND 10 BREECH, HCN	1024	84,513	603				
470	1004-05002	RND 10 BREECH, NH ₃	1024	84,370		2,797			
480	1004-05003	RND 10 BREECH, H ₂ S	1024	85,472			2,249		
488	1004-05004	RND 10 BREECH, NO _x	1024	85,054				49	14,684
497	100416-SC501	ROUND 16, BREECH AEROSOLS	2154	142,358				16	5
498	100419-SC502	ROUND 19, BREECH AEROSOLS	2154	122,129				11	5
499	100421-SC503	ROUND 21, BREECH AEROSOLS	2154	123,173				11	6
	1004-SF04	BACKGROUND AEROSOLS	2154					†	4

† = BELOW DETECTION LIMIT

TABLE 37. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1 - RATIO OF
INORGANIC GASES AND METHANE EMISSION CONCENTRATIONS TO
CARBON MONOXIDE CONCENTRATION

GC RUN NO.	SAMPLE NO.	EMISSIONS COLLECTED	MOLES OF SPECIES PER MOLES OF CARBON MONOXIDE (1)							
			CO2	H2	METHANE	HCN	NH3	H2S	NO ₂	SO ₂
458	1004-01001	RND 2 BREECH, HCN				0.0080				
466	1004-01002	RND 2 BREECH, NH3					0.0121			
476	1004-01003	RND 2 BREECH, H2S						0.0196		
483	1004-01004	RND 2 BREECH, NOx							2.52E-05	2.73E-02
		AVG	0.265	0.949	0.056					
459	1004-02001	RND 4 BREECH, HCN				0.0074				
467	1004-02002	RND 4 BREECH, NH3					0.0141			
477	1004-02003	RND 4 BREECH, H2S						0.0152		
484	1004-02004	RND 4 BREECH, NOx							2.05E-05	2.59E-02
		AVG	0.319	0.831	0.057					
460	1004-03001	RND 6 BREECH, HCN				0.0115				
468	1004-03002	RND 6 BREECH, NH3					0.0501			
478	1004-03003	RND 6 BREECH, H2S						0.0221		
486	1004-03004	RND 6 BREECH, NOx							6.12E-05	4.38E-02
		AVG	0.201	0.976	0.047					
461	1004-04001	RND 8 BREECH, HCN				0.0082				
469	1004-04002	RND 8 BREECH, NH3					0.0524			
479	1004-04003	RND 8 BREECH, H2S						0.0280		
487	1004-04004	RND 8 BREECH, NOx							3.21E-05	4.55E-02
		AVG	0.149	0.976	0.046					
463	1004-05001	RND 10 BREECH, HCN				0.0073				
470	1004-05002	RND 10 BREECH, NH3					0.0543			
480	1004-05003	RND 10 BREECH, H2S						0.0277		
488	1004-05004	RND 10 BREECH, NOx							2.10E-04	3.06E-02
		AVG	0.121	0.946	0.045					
497	100416-SC501	ROUND 16, BREECH AEROSOLS							4.54E-05	7.76E-06
498	100419-SC502	ROUND 19, BREECH AEROSOLS							4.02E-05	1.96E-06
499	100421-SC503	ROUND 21, BREECH AEROSOLS							3.98E-05	5.58E-06
		BREECH GASES	AVG	2.11E-01	9.36E-01	5.00E-02	8.47E-03	3.66E-02	2.25E-02	7.37E-05
		(5 SAMPLES)	RSD	0.385	0.064	0.113	0.203	0.588	0.243	1.032
		BREECH AEROSOLS	AVG	-	-	-	-	-	-	4.31E-05
		(3 SAMPLES)	RSD							0.125

(1) - less levels of each in background.

TABLE 38. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- PAH ANALYSIS RAW DATA

MASS CONCENTRATION OF PAH IN COLLECTED SAMPLES (micrograms/Liter)												
ANALYSIS NO.	EMISSIONS SOURCE	SAMPLE VOLUME (LITERS)	PHEN- ANTHRENE	FLUOR- ANTHRACENE	PYRENE	BENZ-a- ANTHRACENE	CHRYSENE	BENZ-b- FLUORANTHENE	BENZ-k- FLUORANTHENE	BENZ-a- PYRENE	BENZ-ghi- PERILENE	
100412-PC301-6A	ROUND 12, BREECH [FT]	20.0	2.72E-02	↑	1.77E-02	3.48E-02	1.70E-02	2.04E-02	1.49E-02	5.92E-02	1.06E-01	6.36E-01
100412-PC301-6B	ROUND 12, BREECH [BK]	20.0	1.69E-02	↑	5.05E-03	2.27E-03	4.20E-04	3.47E-04	6.00E-05	1.26E-04	1.12E-04	1.08E-04
100414-PC302	ROUND 14, BREECH	20.0	1.41E-02	↑	2.67E-03	4.14E-03	1.85E-03	2.39E-03	1.59E-03	5.60E-03	7.50E-03	6.55E-02
100423-PC303	ROUND 23, BREECH	20.0	2.47E-02	↑	5.05E-03	3.54E-03	7.50E-04	9.35E-04	1.22E-03	3.70E-03	4.72E-03	2.57E-02
1004-14-BKGD	BACKGROUND PAH	20.0	2.72E-03	↑	8.10E-04	↑	6.25E-05	6.55E-05	4.05E-05	1.00E-04	6.90E-05	2.02E-04
1004-15-BLANK	BLANK PAH	0.0	↑	↑	6.10E-04	3.60E-05	↑	↑	3.45E-05	6.40E-05	3.60E-05	1.18E-04
	METHOD BLANK		↑	↑	↑	↑	↑	↑	↑	↑	↑	↑

† = BELOW DETECTION LIMIT; DETECTION LIMITS: 1E-04 TO 5E-03 micrograms/L, RESPECTIVELY; SEE TEXT.

TABLE 39. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- RATIO OF PAH CONCENTRATIONS TO CARBON MONOXIDE CONCENTRATION

MOLES OF PAH SPECIES PER MOLE OF CARBON MONOXIDE (1)												
ANALYSIS NO.	EMISSIONS SOURCE	PHEN-ANTHRENE	ANTHRACENE	FLUOR-ANTHRENE	PYRENE	BENZ-a-ANTHRACENE	CHRYSENE	FLUORANTHENE	BENZ-b-FLUORANTHENE	BENZ-k-FLUORANTHENE	BENZ-a-PYRENE	BENZ-gbi-PERLENE
		=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
100412-PC301	RD 12 BREECH, PAH [SA]	9.83E-08	†	5.99E-08	1.23E-07	5.34E-08	6.40E-08	4.22E-08	1.68E-07	3.03E-07	1.65E-06	
100414-PC302	RD 14 BREECH, PAH	2.65E-08	†	3.83E-09	8.49E-09	3.25E-09	4.24E-09	2.72E-09	9.05E-09	1.22E-08	9.81E-08	
100423-PC303	RD 23 BREECH, PAH	4.56E-08	†	7.77E-09	6.49E-09	1.12E-09	1.41E-09	1.73E-09	5.28E-09	6.84E-09	3.42E-08	
BREECH	10/04/88	5.68E-08	†	2.36E-08	4.61E-08	1.92E-08	2.32E-08	1.55E-08	6.08E-08	1.07E-07	5.95E-07	
		0.555		1.313	1.451	1.537	1.523	1.484	1.528	1.578	1.540	
(1) LESS BACKGROUND LEVELS												

(1) LESS BACKGROUND LEVELS

TABLE 40. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- ALDEHYDE ANALYSIS RAW DATA

ANALYSIS NO	SAMPLE NO.	EMISSIONS SOURCE	MASS CONCENTRATION OF ALDEHYDES (1) (micrograms/Liter)							
			FORM- ALDEHYDE	ACET- ALDEHYDE	ACROLEIN/ ACETONE	PROPION- ALDEHYDE	CROTON- ALDEHYDE	ISOBUTYL- ALDEHYDE	BENZ- ALDEHYDE	HEXAN- ALDEHYDE
=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
6-1P	1004-02-01005	ROUND 2, BREECH	0.18	0.52	22.62	0.09	‡	0.09	0.03	0.19
6-2P	1004-04-02005	ROUND 4, BREECH	0.50	1.35	11.69	0.19	‡	0.23	0.06	0.16
6-3P	1004-25A-03005	ROUND 25[A], BREECH	0.51	0.36	1.87	0.70	0.71	0.35	2.58	0.03
6-4P	1004-25B-04005	ROUND 25[B], BREECH	1.04	0.43	2.55	0.23	0.61	0.21	4.94	0.36
6-5P	1004-25C-05005	ROUND 25[C], BREECH	3.48	0.25	0.45	0.53	0.62	0.20	13.54	0.15
6-6P	1004-06005	BACKGROUND	2.67	0.21	2.10	0.16	‡	0.11	0.08	0.15

(1) COLLECTED SAMPLE VOLUME = 1024 ML/EACH.

‡ = BELOW DETECTION LIMIT (0.01 micrograms/L)

TABLE 41. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- RATIO OF ALDEHYDE CONCENTRATIONS TO CARBON MONOXIDE CONCENTRATION

MOLES OF ALDEHYDE PER MOLE OF CARBON MONOXIDE (1)											
ANALYSTS NO	SAMPLE NO.	SOURCE	ROUND	FORM- ALDEHYDE	ACET- ALDEHYDE	ACROLEIN/ ACETONE	PROPION- ALDEHYDE	CROTON- ALDEHYDE	ISOBUTYL- ALDEHYDE	BENZ- ALDEHYDE	HEXAN- ALDEHYDE
=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
6-1P	1004-02-01005	BREECH	2	8.61E-08	1.69E-07	5.57E-06	2.29E-08	↓	1.70E-08	3.80E-09	1.23E-08
6-2P	1004-04-02005	BREECH	4	1.99E-07	3.64E-07	2.40E-06	3.89E-08	↓	3.69E-08	6.65E-09	7.00E-09
6-3P	1004-25A-03005	BREECH	25[A]	2.27E-07	1.09E-07	4.30E-07	1.62E-07	1.36E-07	6.45E-08	3.25E-07	3.52E-09
6-4P	1004-25B-04005	BREECH	25[B]	6.30E-07	1.75E-07	7.96E-07	7.15E-08	1.58E-07	5.26E-08	9.27E-07	1.16E-08
6-5P	1004-25C-05005	BREECH	25[C]	2.29E-06	1.13E-07	1.55E-07	1.81E-07	1.75E-07	5.48E-08	2.54E-06	3.12E-08
BREECH 10-04-8				AVG (5)	6.86E-07	1.86E-07	9.50E-08	9.38E-08	4.52E-08	7.41E-07	1.31E-08
				RSD	1.339	0.560	6.756	6.925	0.412	1.433	0.816

(1) BACKGROUND NOT SUBTRACTED FROM ALDEHYDE LEVELS.

† = BELOW ANALYSIS LIMITS

TABLE 42. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- SELECTED PARTICULATE METALS MASS CONCENTRATIONS

SAMPLE No.	EMISSIONS SOURCE	MASS CONCENTRATION OF PARTICULATE METALS (micrograms/L)		
		POTASSIUM	LEAD	TITANIUM
1004-GF01	BREECH	879	1.4	1.7
1004-GF02	BREECH	431	0.6	1.3
1004-GF03	BREECH	1523	3.4	10.9
1004-GF04	BREECH	701	1.7	5.4
1004-GF05	BREECH	457	1.2	3.5
1004-GF07	FIELD BLANK	11	*	*
	AVG	798	1.7	4.6
	RSD	171	1.1	3.9

* = BELOW DETECTION LIMIT

DATA FOR THE 155 MM CALIBER, M199 GUN WITH M30A1
PROPELLANT (BREECH AND BORE EVACUATOR SAMPLES)

ALL ROUNDS CONDITIONED AT 125°F.

TABLE 43. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1 - BREECH/EVACUATOR
INORGANIC GASES AND METHANE RAW DATA
(All rounds temperature conditioned to 125°F)

GC RUN NO.	ANALYSIS NO.	EMISSIONS SOURCE	PEAK AREAS				
			CO2	H2	N2	METHANE	CO
=====	=====	=====	=====	=====	=====	=====	=====
29	0310-002	CALGAS, CT2112	7.56E+06	4.72E+06	5.93E+07	2.97E+04	1.49E+07
30	0304-05-601(A)-005	RND 5,BREECH,ALD	5.90E+06	4.75E+06	4.31E+07	1.06E+06	1.62E+07 (1)
31	0304-05-601(B)-005	RND 5,EVACUATOR,ALD	7.62E+06	4.80E+06	4.41E+07	1.44E+06	1.48E+07
32	0310-003	CALGAS, CT2112	7.50E+06	4.45E+06	5.91E+07	3.52E+04	1.48E+07
33	0304-05-601(B)-005	RND 5,EVACUATOR,ALD	7.58E+06	5.20E+06	4.41E+07	1.43E+06	1.47E+07 (1)
34	0310-004	CALGAS, CT2112	7.59E+06	4.63E+06	5.95E+07	3.18E+04	1.48E+07 (1)
35	0304-06-602(A)-005	RND 6,BREECH,ALD	4.09E+06	3.05E+06	5.07E+07	7.51E+05	1.02E+07
36	0304-06-602(B)-005	RND 6,EVACUATOR,ALD	6.63E+06	4.37E+06	4.75E+07	1.15E+06	1.25E+07
40	0310-005	CALGAS, CT2112	#	4.32E+06	5.90E+07	2.90E+04	1.48E+07 (1),(2)
41	0310-006	CALGAS, CT2112	7.47E+06	4.76E+06	5.92E+07	2.95E+04	1.42E+07
42	0313-001	CALGAS, CT2112	7.17E+06	4.67E+06	5.76E+07	#	1.38E+07 (4)
43	0313-002	CALGAS, CT2112	7.31E+06	4.81E+06	5.75E+07	2.84E+04	1.41E+07
44	0307-07[1]-603(A)-005	RND 7[1],BREECH,ALDEHYDE	6.20E+06	7.37E+06	2.20E+07	1.94E+06	3.22E+07 (1)
45	0307-07[1]-603(B)-005	RND 7[1],EVACUATOR,ALDEHYDE	4.42E+06	4.59E+06	3.89E+07	2.04E+06	2.02E+07
47	0307-07[2]-604(A)-005	RND 7[2],BREECH,ALDEHYDE	5.15E+06	7.12E+06	2.91E+07	1.69E+06	2.73E+07 (1)
49	0307-07[2]-604(B)-005	RND 7[2],EVACUATOR,ALDEHYDE	4.20E+06	4.12E+06	3.97E+07	1.98E+06	2.20E+07 (1)
51	0313-003	CALGAS, CT2112	7.27E+06	4.75E+06	5.77E+07	3.59E+04	1.42E+07 (1)
53	0307-07[3]-605(A)-005	RND 7[3],BREECH,ALDEHYDE	4.54E+06	6.16E+06	3.29E+07	1.51E+06	2.35E+07 (1)
55	0307-07[3]-605(B)-005	RND 7[3],EVACUATOR,ALDEHYDE	3.78E+06	4.89E+06	4.01E+07	1.91E+06	1.99E+07
57	0304-606-005	2K6D,ALDEHYDE	3.11E+04	#	6.36E+07	#	#
59	0313-004	CALGAS, CT2112	7.32E+06	4.85E+06	5.84E+07	2.86E+04	1.45E+07
60	0304-05-601(A)-001	RND 5,BREECH,HCN	6.37E+06	4.96E+06	4.57E+07	1.16E+06	1.86E+07
62	0304-05-601(B)-001	RND 5,EVACUATOR,HCN	8.46E+06	5.24E+06	4.64E+07	1.57E+06	1.67E+07
64	0304-06-602(A)-001	RND 6,BREECH,HCN	4.20E+06	3.74E+06	5.55E+07	7.30E+05	1.05E+07
65	0304-06-602(B)-001	RND 6,EVACUATOR,HCN	7.29E+06	4.16E+06	5.12E+07	1.23E+06	1.34E+07
67	0307-07[1]-603(A)-001	RND 7[1],BREECH,HCN	6.73E+06	1.00E+07	3.89E+07	1.90E+06	4.14E+07 (1),(2)
68	0307-07[1]-603(B)-001	RND 7[1],EVACUATOR,HCN	4.73E+06	4.75E+06	4.23E+07	2.17E+06	2.21E+07 (1)
70	0313-005	CALGAS, CT2112	7.12E+06	4.91E+06	5.69E+07	3.03E+04	1.41E+07 (1)
71	0314-001	CALGAS,CT2112	7.20E+06	4.28E+06	5.77E+07	2.72E+04	1.42E+07
73	0314-002	CALGAS,CT2112	7.22E+06	4.71E+06	5.72E+07	2.71E+04	1.43E+07
74	0314-003	CALGAS,CT2112	7.34E+06	4.48E+06	5.31E+07	2.94E+04	1.45E+07
75	0307-07[2]-604(A)-001	RND 7[2],BREECH,HCN	5.66E+06	7.58E+06	3.15E+07	1.83E+06	2.92E+07 (1)
77	0314-004	CALGAS,CT2112	7.22E+06	4.70E+06	5.73E+07	2.66E+04	1.42E+07
79	0307-07[2]-604(A)-001	RND 7[2],BREECH,HCN	5.64E+06	7.11E+06	3.11E+07	1.82E+06	2.45E+07 (1)

TABLE 43. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1 - BREECH/EVACUATOR
INORGANIC GASES AND METHANE RAW DATA (CONTINUED)
(All rounds temperature conditioned to 125°F)

GC RUN NO.	ANALYSIS NO.	EMISSIONS SOURCE	PEAK AREAS				
			CO2	H2	N2	METHANE	CO
81	0307-07[2]-604(B)-001	RND 7[2],EVACUATOR,HCN	4.53E+06	4.92E+06	4.37E+07	2.16E+06	2.19E+07
85	0307-07[3]-605(A)-001	RND 7[3],BREECH,HCN	5.16E+06	6.80E+06	3.58E+07	1.64E+06	2.16E+07 (1)
86	0307-07[3]-605(B)-001	RND 7[3],EVACUATOR,HCN	4.08E+06	4.83E+06	4.49E+07	1.98E+06	2.06E+07
88	0307-606-001	SKGD,HCN	†	†	6.92E+07	†	†
90	0314-005	CALGAS,CT2112	7.09E+06	4.66E+06	5.71E+07	2.54E+04	1.40E+07
92	0304-05-601(A)-002	RND 5,BREECH,NH3	6.64E+06	4.46E+06	4.61E+07	1.13E+06	1.71E+07
96	0314-006	CALGAS,CT2112	7.10E+06	4.34E+06	5.68E+07	2.52E+04	1.41E+07
98	0304-05-601(B)-002	RND 5,EVACUATOR,NH3	8.68E+06	4.73E+06	4.67E+07	1.56E+06	1.59E+07
100	0304-06-602(A)-002	RND 6,BREECH,NH3	4.41E+06	3.54E+06	5.42E+07	7.70E+05	1.05E+07
102	0304-06-602(B)-002	RND 6,EVACUATOR,NH3	7.48E+06	4.64E+06	5.01E+07	1.22E+06	1.33E+07
106	0314-007	CALGAS,CT2112	7.04E+06	4.77E+06	5.62E+07	2.93E+04	1.39E+07
107	0315-001	CALGAS,CT2112	7.34E+06	5.10E+06	5.84E+07	2.92E+04	1.44E+07
108	0307-07[1]-603(A)-002	RND 7[1],BREECH,NH3	6.72E+06	1.00E+07	4.53E+07	1.83E+06	3.52E+07 (1),(3)
110	0307-07[1]-603(B)-002	RND 7[1],EVACUATOR,NH3	5.15E+06	5.43E+06	4.32E+07	2.26E+06	2.25E+07
112	0307-07[2]-604(A)-002	RND 7[2],BREECH,NH3	5.95E+06	7.96E+06	3.15E+07	1.96E+06	2.49E+07 (1)
114	0307-07[2]-604(B)-002	RND 7[2],EVACUATOR,NH3	4.86E+06	5.27E+06	4.38E+07	2.19E+06	2.23E+07
115	0315-002	CALGAS,CT2112	7.29E+06	4.51E+06	5.83E+07	3.38E+04	1.44E+07
117	0304-606-002	BACKGROUND,NH3]	†	7.11E+07	†	†
118	0315-003	CALGAS,CT2112	7.22E+06	5.00E+06	5.84E+07	3.15E+04	1.43E+07
137	0317-001	CALGAS,CT2112	7.47E+06	4.50E+06	5.94E+07	3.04E+04	1.49E+07
138	0317-002	CALGAS,CT2112	7.43E+06	4.86E+06	5.99E+07	2.95E+04	1.49E+07
139	0317-003	CALGAS,CT2112	7.43E+06	4.83E+06	6.02E+07	3.11E+04	1.50E+07
140	0304-05-601(A)-001	RND 5,BREECH,HCN	6.55E+06	4.57E+06	4.77E+07	1.19E+06	1.79E+07
141	0304-05-601(B)-001	RND 5,EVACUATOR,HCN	8.82E+06	4.80E+06	4.81E+07	1.64E+06	1.68E+07
142	0307-07[1]-603(A)-001	RND 7[1],BREECH,HCN	6.85E+06	1.00E+07	3.30E+07	1.88E+06	3.56E+07 (1),(3)
143	0317-004	CALGAS,CT2112	7.18E+06	4.33E+06	5.82E+07	3.75E+04	1.44E+07
144	0307-07[2]-604(A)-002	RND 7[2],BREECH,NH3	5.95E+06	1.00E+07	5.26E+07	1.76E+06	3.27E+07 (1),(3)

- (1) CO ANALYSIS GC PEAK INTEGRATION PROBLEM
(2) CO2 ANALYSIS GC PEAK INTEGRATION PROBLEM
(3) H2 ANALYSIS GC PEAK INTEGRATION PROBLEM
(4) METHANE ANALYSIS GC PEAK INTEGRATION PROBLEM
† BELOW DETECTION LIMIT = 100

**TABLE 44. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1 - BREECH/EVACUATOR
INORGANIC GASES AND METHANE CONCENTRATIONS**

GC RUN NO.	ANALYSIS NO.	EMISSIONS SOURCE	EMISSION CONCENTRATIONS (VOL%)				
			CO2	H2	N2	METHANE	CO
=====	=====	=====	=====	=====	=====	=====	=====
117	0304-606-002	BKGD,NH3	†	†	78.98	†	†
057	0304-606-005	BKGD,ALDEHYDE	0.03	†	71.52	†	†
088	0307-606-001	BKGD,HCN	†	†	78.52	†	†
140	0304-05-601(A)-001	RND 5,BREECH,HCN	7.17	11.96	52.04	1.1134	18.10
060	0304-05-601(A)-001	RND 5,BREECH,HCN	7.12	12.47	51.47	1.1249	19.68
092	0304-05-601(A)-002	RND 5,BREECH,NH3	7.47	11.77	52.28	1.2523	18.03
030	0304-05-601(A)-005	RND 5,BREECH,ALD	6.32	12.49	47.24	1.0231	16.36
062	0304-05-601(B)-001	RND 5,EVACUATOR,HCN	9.44	13.16	52.24	1.5276	17.67
141	0304-05-601(B)-001	RND 5,EVACUATOR,HCN	9.65	12.50	52.48	1.5323	16.99
098	0304-05-601(B)-002	RND 5,EVACUATOR,NH3	9.77	12.48	52.97	1.7216	16.86
031	0304-05-601(B)-005	RND 5,EVACUATOR,ALD	8.17	12.63	48.28	1.3894	14.97
033	0304-05-601(B)-005	RND 5,EVACUATOR,ALD	8.12	13.70	48.30	1.5867	14.85
064	0304-06-602(A)-001	RND 6,BREECH,HCN	4.68	9.40	62.52	0.7590	11.12
100	0304-06-602(A)-002	RND 6,BREECH,NH3	4.96	9.33	61.41	0.6507	11.07
035	0304-06-602(A)-005	RND 6,BREECH,ALD	4.38	9.03	55.51	0.7257	10.32
065	0304-06-602(B)-001	RND 6,EVACUATOR,HCN	8.13	10.45	57.62	1.1937	14.14
102	0304-06-602(B)-002	RND 6,EVACUATOR,NH3	8.42	12.24	56.78	1.3430	14.05
036	0304-06-602(B)-005	RND 6,EVACUATOR,ALD	7.10	11.51	51.97	1.1086	12.63
67	0307-07[1]-603(A)-001	RND 7[1],BREECH,HCN	7.51	25.11	43.87	1.8493	43.80
142	0307-07[1]-603(A)-001	RND 7[1],BREECH,HCN	7.50	26.03	41.52	1.7521	36.05
108	0307-07[1]-603(A)-002	RND 7[1],BREECH,NH3	7.45	24.75	50.38	1.7381	36.70
044	0307-07[1]-603(A)-005	RND 7[1],BREECH,ALD	6.91	18.51	24.83	1.6922	34.07
068	0307-07[1]-603(B)-001	RND 7[1],EVACUATOR,HCN	5.27	11.92	47.64	2.1153	23.38
110	0307-07[1]-603(B)-002	RND 7[1],EVACUATOR,NH3	5.71	13.45	47.95	2.1524	23.40
045	0307-07[1]-603(B)-005	RND 7[1],EVACUATOR,ALD	4.93	11.52	43.84	1.9831	21.33
075	0307-07[2]-604(A)-001	RND 7[2],BREECH,HCN	6.36	20.02	35.68	2.0197	30.39
079	0307-07[2]-604(A)-001	RND 7[2],BREECH,HCN	6.34	19.77	35.28	2.0081	25.86
144	0307-07[2]-604(A)-002	RND 7[2],BREECH,NH3	6.51	26.03	57.45	1.6454	33.12
112	0307-07[2]-604(A)-002	RND 7[2],BREECH,NH3	6.60	19.69	35.00	1.7693	25.95
047	0307-07[2]-604(A)-005	RND 7[2],BREECH,ALD	5.74	17.87	32.75	1.6450	28.89

TABLE 44. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1 - BREECH/EVACUATOR
INORGANIC GASES AND METHANE CONCENTRATIONS (CONTINUED)

GC RUN NO.	ANALYSIS NO.	EMISSIONS SOURCE	EMISSION CONCENTRATIONS (VOL%)				
			CO2	H2	N2	METHANE	CO
=====	=====	=====	=====	=====	=====	=====	=====
081	0307-07[2]-604(B)-001	RND 7[2],EVACUATOR,HCN	5.10	12.99	49.56	2.3807	23.10
114	0307-07[2]-604(B)-002	RND 7[2],EVACUATOR,NH3	5.39	13.04	48.89	2.0627	23.19
049	0307-07[2]-604(B)-005	RND 7[2],EVACUATOR,ALD	4.68	10.34	44.77	1.9257	23.28
085	0307-07[3]-605(A)-001	RND 7[3],BREECH,HCN	5.81	17.95	40.55	1.8129	22.79
053	0307-07[3]-605(A)-005	RND 7[3],BREECH,ALD	5.07	15.47	37.01	1.4682	24.86
086	0307-07[3]-605(B)-001	RND 7[3],EVACUATOR,HCN	4.59	12.75	50.85	2.1874	21.78
055	0307-07[3]-605(B)-005	RND 7[3],EVACUATOR,ALD	4.41	12.28	45.22	1.8615	21.01
029	0310-002	CALGAS, CT2112	8.10	12.42	64.91	0.0287	15.04
032	0310-003	CALGAS, CT2112	8.04	11.72	64.76	0.0340	14.95
034	0310-004	CALGAS, CT2112	8.13	12.20	65.20	0.0308	14.99
040	0310-005	CALGAS, CT2112		11.36	64.59	0.0280	14.99 (1)
041	0310-006	CALGAS, CT2112	8.01	12.54	64.84	0.0285	14.98
042	0313-001	CALGAS, CT2112	7.99	11.73	64.82		14.83 (2)
043	0313-002	CALGAS, CT2112	8.15	12.08	64.71	0.0277	14.97
051	0313-003	CALGAS, CT2112	8.11	11.92	65.00	0.0350	14.99
059	0313-004	CALGAS, CT2112	8.16	12.19	65.73	0.0279	15.37
070	0313-005	CALGAS, CT2112	7.94	12.33	64.03	0.0295	14.92
071	0314-001	CALGAS, CT2112	8.10	11.31	65.44	0.0301	15.04
073	0314-002	CALGAS, CT2112	8.12	12.44	64.96	0.0299	15.10
074	0314-003	CALGAS, CT2112	8.26	11.83	65.92	0.0324	15.37
077	0314-004	CALGAS, CT2112	8.12	12.42	65.01	0.0294	15.03
090	0314-005	CALGAS, CT2112	7.97	12.29	64.69	0.0280	14.83
096	0314-006	CALGAS, CT2112	7.99	11.47	64.40	0.0278	14.86
106	0314-007	CALGAS, CT2112	7.92	12.58	63.70	0.0324	14.70
107	0315-001	CALGAS, CT2112	8.13	12.62	64.89	0.0278	15.05
115	0315-002	CALGAS, CT2112	8.08	11.16	64.82	0.0322	14.98
118	0315-003	CALGAS, CT2112	8.00	12.37	64.87	0.0300	14.94
137	0317-001	CALGAS, CT2112	8.17	11.71	64.83	0.0283	15.07
138	0317-002	CALGAS, CT2112	8.13	12.65	65.38	0.0276	15.11
139	0317-003	CALGAS, CT2112	8.13	12.58	65.70	0.0291	15.18
143	0317-004	CALGAS, CT2112	7.85	11.26	65.53	0.0350	14.60

* BELOW DETECTION LIMIT

@ SAMPLE ANALYSIS ABANDONED DUE TO GC PEAK INTEGRATION PROBLEMS.

(1) CO2 GC PEAK INTEGRATION PROBLEMS

TABLE 45. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- BREECH/EVACUATOR HCN ANALYSIS RAW DATA

(1)		
SAMPLE NO.	EMISSIONS SOURCE	TOTAL CYANIDE (mg/L)
=====	=====	=====
1504-01A-001	RND 5, BREECH	4.91
1504-02A-001	RND 6, BREECH	13.12
1504-03A-001	RND 7 [1], BREECH	50.70
1504-04A-001	RND 7 [2], BREECH	23.10
1504-05A-001	RND 7 [3], BREECH	10.50
1504-01B-001	RND 5, EVACUATOR	0.11
1504-02B-001	RND 6, EVACUATOR	0.18
1504-03B-001	RND 7 [1], EVACUATOR	0.52
1504-04B-001	RND 7 [2], EVACUATOR	0.13
1504-05B-001	RND 7 [3], EVACUATOR	0.10
1504-06-001	BACKGROUND	1.48
1520-10-001	HCN SOLUTION BLANK	0.05
1520-11-001	HCN STANDARD (19.17 mg/L)	18.90

(1) SOLUTION VOLUME = 50 ml
DETECTION LIMIT = 0.1 mg/L

TABLE 46. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1
- BREECH/EVACUATOR NH3 ANALYSIS RAW DATA

(1)		
SAMPLE NO.	EMISSIONS SOURCE	AMMONIA-N (mg/L)
=====	=====	=====
1504-01A-001	RND 5, BREECH	27.3
1504-02A-001	RND 6, BREECH	20.7
1504-03A-001	RND 7 [1], BREECH	8.25
1504-04A-001	RND 7 [2], BREECH	9.9
1504-05A-001	RND 7 [3], BREECH	(2)
1504-01B-001	RND 5, EVACUATOR	7.75
1504-02B-001	RND 6, EVACUATOR	7.18
1504-03B-001	RND 7 [1], EVACUATOR	10
1504-04B-001	RND 7 [2], EVACUATOR	8.23
1504-05B-001	RND 7 [3], EVACUATOR	(2)
1504-06-001	BACKGROUND	0.61
1520-10-001	NH3 SOLUTION BLANK	0.26
1520-11-001	NH3 STANDARD, 17.38 mg/L	16.8

(1) SOLUTION VOLUME = 50 ml
(2) SAMPLE FLASK FRACTURED IN TRANSIT
* DETECTION LIMIT (0.1 mg/L)

TABLE 47. GUN, M199; BORE, 155 MM; PROPELLANT, M30A1 - BREECH/EVACUATOR
MASS CONCENTRATION OF COLLECTED INORGANIC GAS EMISSIONS

GC RUN NO.	SAMPLE NO.	EMISSIONS SOURCE	VOLUME (nl)	MASS CONCENTRATION OF GASES (micrograms/Liter)		
				CO	HCN	NH3
=====	=====	=====	=====	=====	=====	=====
060	1504-01A-001	RND 5 BREECH, HCN	1024	215,242	249	
092	1504-01A-002	RND 5 BREECH, NH3	1024	197,142		1621
064	1504-02A-001	RND 6 BREECH, HCN	1024	121,577	666	
100	1504-02A-002	RND 6 BREECH, NH3	1024	121,097		1229
067	1504-03A-001	RND 7[1] BREECH, HCN	1024	496,819	2572	
108	1504-03A-002	RND 7[1] BREECH, NH3	1024	416,241		490
079	1504-04A-001	RND 7[2] BREECH, HCN	1024	350,337	1172	
112	1504-04A-002	RND 7[2] BREECH, NH3	1024	294,276		568
085	1504-05A-001	RND 7[3] BREECH, HCN	1024	258,496	533	
062	1504-01B-001	RND 5 EVACUATOR, HCN	1024	193,255	6	
098	1504-01B-002	RND 5 EVACUATOR, NH3	1024	184,386		440
065	1504-02B-001	RND 6 EVACUATOR, HCN	1024	154,650	9	
102	1504-02B-002	RND 6 EVACUATOR, NH3	1024	153,666		426
068	1504-03B-001	RND 7[1] EVACUATOR, HCN	1024	265,210	26	
110	1504-03B-002	RND 7[1] EVACUATOR, NH3	1024	265,428		594
081	1504-04B-001	RND 7[2] EVACUATOR, HCN	1024	262,009	7	
114	1504-04B-002	RND 7[2] EVACUATOR, NH3	1024	262,981		489
086	1504-05B-001	RND 7[3] EVACUATOR, HCN	1024	247,022	5	
088	1504-06-001	BACKGROUND, HCN	1024	‡	75	
117	1504-06-002	BACKGROUND, NH3	1024	‡		36

‡ = BELOW DETECTION LIMIT